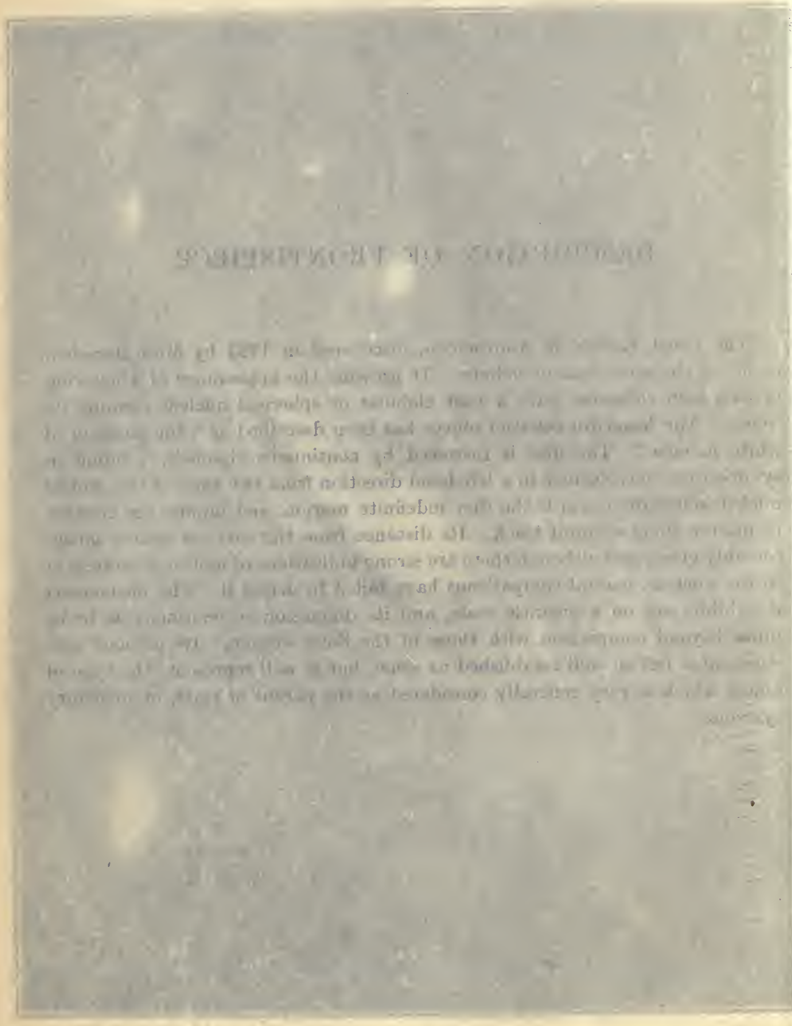
FRONTISPIECE.

THE GREAT NEBULA IN ANDROMEDA.

Yerkes Observatory Photograph.

DESCRIPTION OF FRONTISPIECE.

The Great Nebula in Andromeda, discovered in 1783 by Miss Herschel, is one of the most famous nebulæ. It presents the appearance of a flat ring or disc seen edgewise, with a vast globular or spherical nucleus forming its centre. The beautiful celestial object has been described as "the paragon of white nebulæ." The disc is furrowed by continuous channels, winding in symmetrical convolutions in a left-hand direction from two sides of the central nucleus outwards towards the dim indefinite margin, and implies the ejection of matter along a spiral track. Its distance from the earth is almost inconceivably great, and although there are strong indications of motion with respect to the nucleus, careful comparisons have failed to detect it. The phenomena it exhibits are on a gigantic scale, and its dimension so enormous as to be quite beyond comparison with those of the Solar system. Its gaseous constitution is not so well established as some, but it well represents the type of object which is very generally considered as the parent of stars, or planetary systems.



THE GREAT NEBULA IN ANDROMEDA

THE EARTH:

ITS GENESIS AND EVOLUTION

CONSIDERED IN THE LIGHT OF THE MOST RECENT SCIENTIFIC RESEARCH.

BY

A. T. SWAINE.

With Plates and other Illustrations.

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PREFACE.

The problem of the earth's origin has proved itself to be a fascinating theme in every generation. Imaginative philosophers, keen-visioned seers, and calculating and observant scientists have each in turn endeavoured to provide a solution. Interest in the question has been perpetuated by its continued elusion of those who search its depths. The sign of the earth's true beginning is yet shrouded in mystery. Research has thrown a burning light upon the hypotheses of yesterday, but each theory in the long succession has manifested a small amount of enduring truth. Past efforts have not failed to contribute to the store of knowledge which lasts from generation to generation. As the centuries pass, what has proved itself of good report combines with every new discovery and points to eventual success.

The preparation of the present volume has been carried out with these thoughts in mind. The desire has been to gather up the conclusions of the past and to incorporate, as far as possible, the results of recent research, in order to evolve an up-to-date story of the earth. How far this attempt will endure the criticism of expert knowledge only time will tell, but it is hoped that interest in the subject will be deepened.

The work, as now completed, appears to harmonise with the most recent views of the origin of matter in a way that was not anticipated when the author commenced his manuscript. Recent deductions from numerous phenomena of the universe, arrived at by the most abstruse calculations and reasoning, have traced the origin of the whole of the material universe to a common basis. The opinion that matter is materialised force is steadily gaining

adherents, and it is claimed for the present work that it is a corroboration of these important deductions, from considerations concerning that portion of the material universe which is accessible to detailed observation. Hitherto it has been based upon abstract reasoning regarding the laws and forces which dominate matter. Now it is based, not only in abstract thought, but in concrete fact. The testimony of the rocks confirms the requirements of law. The method of reasoning in each case commences at opposite extremes, but the conclusion is one and the same. Seeing that the confirmation was unforeseen and unexpected, it is of the nature of a true deduction, which must enhance its value.

A three-fold interest is awakened by these studies—viz., (1) The Geologist, as the evidence upon which the principal conclusions are based is largely derived from geological authorities, and is likely to provoke discussion in the different schools of thought. The important points of technical interest being (*a*) the origin of sedimentary rocks by analogy with modern ocean deposits; (*b*) the phenomenon of ocean transgressions and their causes, and the part they have played in the architecture of the earth's crust. (2) The Metaphysician, inasmuch as the modern theory of the relation of energy and matter finds strong confirmation in the facts recited. (3) The General Reader, interested in this great theme, who is not strictly scientific, will find the language used is, as far as possible, popular and devoid of difficult and unfamiliar expressions.

It may also be of value to point out that the much-discussed topic of geological time, or the age of the earth, has been designedly omitted. This is a purely speculative subject, and in the absence of any suitable standard of measurement, it is of little scientific or general value. Moreover, our language is not adequate to convey an impression of the enormous duration of the various geological epochs or of the aggregate time they represent.

The use of extravagant terms in the description of past geological

phenomena has also been avoided. This is necessitated by the natural prejudice which exists against magnifying the natural forces of the past. There is a reluctance to grant to nature powers greater than she at present exerts. It is only just, however, to observe that those who describe more recent manifestations of natural force too often exceed proper bounds, for it is habitual to magnify the present. It is not intended that the terms here made use of should be interpreted in any other than their accustomed sense.

In conclusion, the author expresses his deep obligation to the large company of investigators whose researches have made possible this thesis, and he also desires to thank his publishers for most valuable suggestions whilst the work has been at press, and for their careful oversight of the proofs. The preparation of the work has been of absorbing interest to the author, and it is hoped will prove helpful to other searchers after truth.

A. T. SWAINE.

LONDON, *April*, 1913.

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CHAPTER I.

THE EARTH'S BEGINNING.

Stellar Cycles—Novæ and Stellar Cycles—Various Theories of Planetary Genesis—Inconsistency of "Nebular Hypothesis"—The Problem to be Discussed—Stellar Cycles and Combustion—The Fundamental Process Involved—In Harmony with the Nebular Hypothesis—Aqueo-organic Theory and the Ether—The Sun and the Revised Hypothesis—Early Constitution of Solar System—Commencement of Earth Building—Support of other Branches of Science.

The basis of every reasonable theory of the earth's beginning must be centred in what we know of the heavenly bodies. The system of which the earth forms a unit is probably one of many multitudes of similarly constituted clusters among the stars, and made visible by the telescope. These clusters are infinite in variety, and may be divided into groups which appear to indicate different degrees of development. Evolution probably plays as important a part in the Celestial economy as in the Terrestrial, although science is too young and too short-lived for this to be demonstrated. If this is the case, the evolution of the earth will not only commence with data derived from the study of the stars, but will assuredly contribute to our knowledge of them. The earth is not only a unit of the Solar system, but this again, is a system among systems, so that, while the solar cluster cannot be considered as distinct from all others, so the earth cannot be treated as separate from the system of which it forms a part. The successful theory must preserve that system in its unity, and the earth's evolution must be directly associated with the evolution of the system.

Stellar Cycles.—The primitive class of stars, which are believed to be the initial stage in the cosmic process, are composed of elements in a highly divided or free molecular state. They are little more than masses of cosmic fog, or nebulæ. Much higher in the scale are the stars, whose light reveals the presence of a variety of minerals in their constitution; they are closely related

to our Sun. Another class exists in considerable numbers: the Dark Stars; but the bare record of the existence of these phases of stellar evolution is of limited interest compared with the enthusiasm kindled by the knowledge that changes from one state to another are not infrequent. The nebular phase is not only the primary, but also the final state, and a planetary system may commence in the gaseous fog, pass through many stages of evolution, and return again to the nebular; then a new cycle of operations may commence where the last one originated.

Novæ and Stellar Cycles.—This evolution may not be continuously progressive, but may be retarded, or arrested, and the planetary orbs may remain in a state of arrested evolution for untold eras, after which another phase may be entered upon. This may be illustrated respectively by the Dark Stars and Novæ. The latter have established themselves in the regular economy of nature, and are stars which come into prominence with more or less rapidity. The "Star of the New Century," for instance, was first observed on February 20, 1910, after it had been gaining in strength for several days. Its greatest magnitude was reached on the 23rd; the next day it was much less luminous, and it continued to fade, until in July it had become nebulous. Towards September, the gases had expanded and occupied a far greater volume.

These Novæ may be derived from Dark Stars by their sudden illumination, and those which have been closely observed have gone through a regular cycle, and a planetary nebula has replaced the luminous star. During the early phase of these cycles, the spectra of the Novæ suggests resemblances between them and the Solar Chromosphere, although they are on a grander scale of magnificence. The light is exceedingly unstable at first, and indicates the enormous disturbances in the vaporous matter. Afterwards, the light declines, but ever and again temporarily recovers and the colour varies from red to white, and from clear orange to a purplish glow. The flickering conflagration slowly dies down like the flames of a burning building. The combustion is sometimes so complete that the metallic vapours radiate into space, and only hydrogen remains as a luminous haze, and the cycle is complete.

This stage of the cycle represents the decease of a Dark Star, and the return to the original nebula. The initial stage of the new cycle, back from the gaseous to the dark star, is not observable in the heavens, but we may suppose that this is ever in progress. In this case, the Nebulæ, Dark Stars, and Suns are systems, or units in different stages of progressive or arrested evolution. For instance, if a Nova were arrested when giving a fraction of its initial light, it would be comparable to the Sun in luminous power, and might indeed deserve that name.

If, as has been suggested, stars which are comparable with our Sun in mineral composition are evolved from primitive nebulæ,

and are at the same time Novæ in a state of arrested evolution, as may be the case, Dark Stars are themselves also derived from similar nebulæ; it is this stage which requires explanation, since they are the heavenly bodies which might be compared with the Earth and Moon with evident reason, although it is not suggested that the Earth and Moon represent the same evolutionary phase.

Various Theories of Planetary Genesis.—We have seen how the nebular haze or cosmic fog may be derived from an apparently solid or molten star, but how the reverse operation is performed and a solid body derived from the gaseous is not so easily demonstrated. The more generally accepted theory of the earth's beginning does trace it from an original ancestral nebula, but the working out of that hypothesis has been surrounded by serious objections on many grounds. The Meteoritic hypothesis of Lockyer and Darwin, as well as the Planetesimal theory of Chamberlain, commence at a much later stage than the nebular, since the former requires a swarm of meteorites or fragments of pre-existing planets and the latter postulates a Solar System in its entirety, with the nucleus of the present planets already in existence.

Inconsistency of "Nebular Hypothesis."—The Nebular Hypothesis commences with matter in its simplest state, but the next step, in which it supposes that the gaseous mist must pass by cooling directly to a molten liquid, has at least no foundation in known facts. We are familiar with the change from gas to water, or other liquid, at excessively low temperatures, but this theory requires the change to take place at exceedingly high temperatures. While we are without knowledge of the behaviour of metallic vapours under such conditions, it is unsafe to base an argument upon the supposition that they follow the ordinary laws of condensation, especially if it can be shown that it is inconsistent with well-established laws of chemistry.

The proposition that requires to be demonstrated, if the Nebular theory, as it is stated, is valid, is that cosmic fog or nebula is directly reduced, to the liquid or molten state, in the same way that steam becomes water simply by fall of temperature. The change from steam to water is a restriction of molecular freedom as the temperature falls, and is a molecular change only. Now, the molten material from which many rocks have solidified was composed of minerals consisting of simple elements in complex chemical union, so that the passage from a nebular to a molten state would require a chemical as well as a molecular change, and would bear no comparison with that induced merely by fall of temperature.

The validity of the nebular theory, as at present understood, thus centres in its ability to satisfy known laws of chemistry. One question of crucial import needs an adequate answer, Will fall of temperature in a heterogeneous assembly of metallic vapours produce those chemical combinations represented in the minerals

of which rocks are composed? Will cooling effect the union of silicon and oxygen to form silica, or of carbon and oxygen to form carbonate of lime, or of hydrogen and carbon to form hydrocarbons? all of which are important rock-forming constituents.

Silicon, carbon, and oxygen are stable elements. When they become united, the silica and carbonate of lime are less stable compounds. That is to say, statical changes have been accomplished by the re-arrangement of atoms. The atomic re-arrangement has been occasioned by redistribution of energy, as evinced by the instability. The neutrality of the original energy endowment, if it existed, has been altered to potentiality, and energy must have been exerted in the process. It is stored up in the minerals, and may be recovered in the form of heat and light by simple combustion. Chemical union is thus a positive process, and cannot be effected by fall of temperature. It is evolutionary, not merely thermal.

The relationship of energy and matter and the fundamental process in nature by which minerals are produced are further discussed in the constructive argument.

The Problem to be Discussed.—It is a simple and well understood dictum that there are three states of matter—the Gaseous, Liquid, and Solid. The condensation of steam into water and the change from water to ice, at successive lower temperatures, is an illustration, and the reduction of the air we breathe to the liquid and semi-solid state at exceedingly low temperatures and high pressures is a second. The converse process may be illustrated in the fusion of metals at high temperatures, but whether the chemical changes which take place at the surface of a molten mass of metal, whereby the dissolution of certain elements is effected, could be re-adjusted merely by cooling is probably beyond experiment. It is this re-adjustment, or process of chemical combination of the simple elements, which confronts the theorist who desires to trace the evolution of the earth from a nebula.

It thus becomes necessary at the outset to indicate a process by which a planet, such as the earth, may be evolved from a primitive nebula, such as has already been referred to. Only recognised laws of nature may be appealed to, and facts of astronomical research must be the basis of the theory. The following introductory outline will be corroborated and amplified by the geological deductions of the earlier chapters which follow, where the order of the process is worked out in greater detail.

Stellar Cycles and Combustion.—The molten state of matter is an intermediate phase of the process of combustion, between ignition and complete combustion, and is represented in the stellar economy by the conflagration of the Dark Stars and the production of Novæ. Combustion is a process by which simple elements, in chemical union in the solid form, are torn asunder or decomposed. While it is in progress these elements may form new combinations,

either among themselves, or with the oxygen which is essential to the process. With the high temperatures, however, which are at command in the stars, these new combinations are but temporary, and in the completed process all unity is apparently lost, and the elements return to their simplest and freest molecular state. This is witnessed in the last stages of a Nova, when only the hydrogen remains luminous to the spectroscope. Combustion is retrogression, not progression.

It is conceivable that combustion may be arrested in the molten state to produce a solid, if cooling intervened or on account of lack of oxygen, and such appears to be the case with the Moon ; but this particular phase would still be a stage in the retrogression. This solidification of the molten liquid is supposed to be the third step in the Nebular theory, so that in a double sense it places devolution before evolution.

Fundamental Process Involved.—We have, therefore, to provide the evolutionary portion of the cycle for the production of the solid material in order that devolution may ensue. The only means outside the experimental laboratory whereby solid rock material is produced from simple elements is through the instrumentality of a force which is competent to effect exactly the opposite phenomena to combustion—namely, the union of elements which fire disunites.

There is a fundamental process in nature by which substances are produced from these simple elements. The initial stage is accomplished through the intervention of the vital force of life, in organisms provided with green colouring matter or "leaf green," when placed within the required environment ; and that environment is water. Protoplasm living in water assimilates carbon-dioxide and water, and at the same time changes light energy received from exterior sources into heat energy. Some of the elements of the carbon dioxide and water enter into new combinations and molecules of organic substance in the form of hydrocarbons, sugars, and the like, are built up ; other salts are believed to play some part in the process, but do not enter into the new compounds. It is the vegetable world which performs this operation, and free oxygen is liberated. The animal kingdom feeds upon the spare oxygen supplied in this way, together with the vegetable food and exhales carbon dioxide. In this way progress is made from the elementary or gaseous state through the vegetable to the animal kingdom, and in both processes tissues are built up.

The heat energy received in this way is conserved in the tissues, and may at any time be reclaimed for useful purposes by ignition and combustion. Vegetation, for instance, stores up light and heat, and in the fire gives back the same amount of energy in the original form.

Water is, therefore, the intermediate state between the nebula

and the solid earth, and organic life is the instrument by which the change from the second to the third state is accomplished. The aqueous phase is intermediate between the nebula and the Dark Star. The Nova represents the subsequent or igneous stage in the Stellar physics. The true sequence of events is consequently as follows :—

GASEOUS—AQUEOUS—LITHEOUS—IGNEOUS.

In Harmony with the Nebular Theory.—This appears to be corroborated by the spectrum analysis of the original nebulæ. It is to be remarked that hydrogen survives in the Novæte conflagrations, and is the principal constituent of primitive cosmic fog. Oxygen, nitrogen, silicon, and certain metallic vapours have also been detected in the spectra. Oxygen is not only present, but is required for the process of combustion, so that it is probable that the separation of the oxygen and hydrogen is the very last stage of the sequence. Having been thus set free ; when the heat is dispersed into space and cooling effected, the last elements to be disunited may be the first to enter into combination, although the new association may not be the same as the previous one. It is not, therefore, beyond the realm of possibility that these two gases unite to form water, or steam, which afterwards condenses to water.

With a slight modification, the "Nebular Hypothesis" is in full accord with this. Although it places the molten stage in an anomalous position in the sequence of events, it does require that in process of time, when cooling was sufficiently advanced, water condensed from the remaining nebulous atmosphere. If this condensation is placed a degree further back in time, the essential details of the theory are preserved, and the necessary aqueous medium for the production of the solid by organic means is provided.

Aqueo-organic Theory and the Ether.—Thus far we have traced a succession of changes which may be reasonably supposed to take place in the process of cosmic evolution. It is merely a linking-up of known phenomena which are present in the visible universe around us. Luminous gas is on the border line between the visible and invisible. Beyond that line matter enters the state in which it leaves no impression upon the sight, but at the same time may be experienced by other senses. For instance, the reason detects the presence of the atmosphere by inference from observed results. It resists our power of locomotion, and when itself in motion causes waves to rise and fall and trees to bend before it.

This method of deduction has been made use of to trace the origin of the material universe to an even more elementary source. "The ultimate basis of matter, as far as it is in any way accessible

to observation, is the formless ether," which may then be placed before the gaseous and be the primal state of all. The whole of the material universe may thus be traced to a common original basis. This universal ether was originally endowed with energy, which may be considered as without difference of potential or strain. The energy was uniformly distributed throughout, and in a neutral state, but since "all the phenomena of the material universe may be considered as arising solely from changes in energy distribution," the origin of that material universe may be attributed to change of potentiality in the original and universal ether. In this way it is believed that energy is the sole ultimate phenomenal basis of matter,[1] and it is rendered phenomenal or observable by that change of potential in the same sense that the presence of the atmosphere is impressed upon the mind in the alternation of storm and calm, which are the result of potential change.

Exactly how the change of energy distribution in the ether accounts for the origin of matter in its simplest or gaseous state is not known, but the greater conclusion includes the less, so that gas is but semi-materialised force. The next step from the gaseous to the liquid state is more easily understood. If now vital force may be considered as a peculiar manifestation of the change of potential in the ether, operating in an aqueous medium, the aqueo-organic theory of the earth's formation forms a definite link in the chain of events from ether to matter.

Tunzelmann concludes that the extended activity required to account for the material order of nature contains no characteristics differing in kind from those observed in all living organisms, and considers that it is an established scientific theory. If, therefore, this is true in the broader sense, it carries with it the minor conclusion if the true sequence of events is made out. The organic origin of the earth's crust is, therefore, more than mere supposition.

The Sun and the Revised Hypothesis—The question of the sun's evolution in relation to this deduction is of vital importance, and needs separate consideration. If the nebular hypothesis is applicable to the origin of the sun, it requires that for all time in the history of the Solar System, the central orb has been growing cooler, and may now be considered as in an intermediate state between an incredibly hot gas and a cold body. We have no evidence, however, whether the sun is growing colder or hotter. If it is still in a gaseous state and dispensing heat, paradoxical as it may seem, it is growing hotter on account of decreased bulk. If, on the other hand, it is solid beneath the flaming chromosphere, it is probably decreasing in temperature.

There is one fact that is fully demonstrated. It is radiating energy into space with almost unbounded prodigality. An incessant

[1] G. W. de Tunzelmann, *Electrical Theory and Problem of the Universe*, 1910, p. 470

flood of light and heat energy is dispersed into space in all directions on account of its exceedingly high temperature, and it is only a minute fraction of this which reaches the earth. A great quantity of energy is also expended in the projection into space of the gaseous prominences. Vast incandescent masses of gas frequently shoot upward with incredible velocity, and reach altitudes of 300,000 miles. The velocity of projection frequently exceeds 200,000 miles per hour. In addition to this, the disintegration of radio-active substances is continually in progress, and perhaps indicates the dissipation of a relatively greater quantity of energy than the dissolution of the chemically combined atoms.

The sun is thus a vast storehouse of energy, and the continued emission makes no apparent difference to the supply. If, therefore, the usual supposition that the Sun has for all time been engaged in this almost profligate expenditure of heat, at an exceedingly high potential, the reason is confronted with a proposition it is unable to accept. The Sun cannot give out what it did not receive.

The derivation of Solar energy is one of the unsolved problems of astronomy. That it must have gathered this during some portion of its history is certain. It is consequently necessary to inquire if the organic storage of heat will throw light upon this question, and also to ascertain if so stupendous a change as is required for the Sun to pass from a non-self-luminous to a luminous state is recorded in the known facts of geology.

This theory of Planetary evolution has much that is in keeping with Stellar phenomena. It traces the development of the Dark Star from the nebula, and it is not improbable that many stars and planets have evolved in the same way. The spectrum of the Sun reveals a mineral constitution not widely different from that of the earth, so that both may owe their derivation to the same cause. If the theory is applicable to the whole of the Solar System, it requires that even the sun was originally a Dark Star evolved from a nebula. We are not without knowledge that this may have been the case. The geological record, as we shall see, shows that during the early stages of its history, the earth did not receive its illumination from that source, in fact not until after more than half of its crust had been built up. The light and heat of the Sun did not reach the earth until late in geological time. This suggests that the Sun changed to its present igneous state at that period, and is now dispensing light and heat, by the simple process of combustion, which was stored up within it by organic means in the remote ages of the past, and is now in a state of retrogression. The earth, on the other hand, is still in progress of formation. It is receiving light rays, and has an atmosphere and hydrosphere within which the construction of organic tissues is going on in the animal and vegetable kingdoms.

Early Constitution of Solar System.—The constitution of the

Solar system at this early period may now be described. By the process of evolution a spiral form of nebula was developed from a more simple type, an illustration of which forms the frontispiece, in which knots of gaseous constitution were revolving at high velocity around a central and larger volume of similar gas. Condensation then commenced either in some or all of the nebular nuclei, according to circumstances, and eventually all cooled down to form the aqueous nuclei of the planets. These globes of condensed vapour or hydrospheres all revolved about a common centre, and in the same order in which they now move.

The aqueous condition may have arrived much earlier in some instances than in others, but, as soon as the required state was reached, and the conditions were conducive to the propagation of life, those processes commenced in the living protoplasm which initiated the evolution of the solid crust within the planetary hydrosphere. This was repeated in other centres as soon as the favourable point was reached, or was simultaneous in all, if circumstances permitted.

Commencement of Earth-building.—From this point onwards the principles and mechanics of Chamberlain's Planetesimal Hypothesis are followed very closely, the basis of which is that the globe was formed by the accretion of cold matter, which basis it is believed will stand,[1] the only difference being the source of the material which built up the crust. Instead of being constructed by the accession of planetesimal or meteoritic material which concentrated within the nuclei, the terrestrial envelope was originated by the slow accretion of infalling organic substance in the form of casts, tests, shells, spicules, and frustules of low forms of protozoa and other marine forms evolved from the protoplasm and similar to those which inhabit the oceans to-day. The ceaseless propagation of life in the suited environment produced a constant and never ceasing rain of material within the respective hydrospheres. The orderly way in which this was accomplished will appear in later chapters.

Throughout subsequent ages of the earth's history, more and more material was accumulated in this way until, as in the Planetesimal theory, radio-activity, or the disintegration of radio-active substances, together with the compression due to the increase of mass, raised the heat of the interior so as to melt it, and the hot fluid was transferred to the surface. This was again buried under new organic strata until the further increase of mass caused renewed volcanic activity. Geological discovery points to the fact that each of the greater volcanic episodes was accompanied by a withdrawal of the oceans from large parts of its bed. When the igneous activity had ceased, the oceans again transgressed the land previously laid bare, and a new system of organic sediments was laid

[1] H. S. Fairchild, "Geol. under the Planetesimal Hypotheses." *Bull. Geol. Soc. Am.*, vol. xv., 1904, p. 243.

down. These cycles were repeated until the earth assumed its present form.

Support of other Branches of Science.—There is also other evidence, both of a negative and positive nature, which further tends to corroborate the aqueo-organic theory, and although dealt with more fully in the narrative, may be briefly mentioned here. Any rocks within the earth which might have once formed part of the molten spheroid of nebular origin have become fewer with increasing research. A recent writer has said that, "the assumption that we can find anywhere the primordial solid crust of the globe must be definitely abandoned."[1] If it existed, which is now a matter of speculation, it has been melted again and again. Not only does geology controvert the igneous hypothesis, but it strongly supports the organic. Further, support is also contributed by Darwin's theory of descent, which, as we shall see, requires the existence of life so far back in the dim ages of antiquity that the dawn of life must have preceded the time at which the earth is supposed to have originally cooled down. In this way Astronomy, Geology, and Darwinian Evolution combine to probe the mystery of the untold past.

[1] F. Lœwinson Lessing, "The Origin of Igneous Rocks." *Geol. Mag.*, 1911, p. 294.

CHAPTER II.

OUR PLANET.

The Relative Proportions of the Earth—The Relative Motions of the Earth—Extent of Land and Ocean Compared—Stratified Rocks and Earth Disturbances—The Geological Rock Systems—The Problem and Method of Interpretation.

A STATEMENT, indicating the dimensions and setting of the Earth in the Starry Universe, will serve as a fitting prelude to a study of its structure. It will, at the same time, tend to give due proportion to our thoughts concerning it. In relation to the Solar System in which it is set, it is comparatively insignificant, being surrounded by vast globes, which move in the greater vastness of Space. It is but a star wandering among the multitude of the heavens.

The Solar System embraces eight planets; each of which revolves round the Sun in an approximately circular path relatively to it as a centre. The four which are nearest to the Sun, are Mercury, Venus, the Earth, and Mars. These are termed the inferior planets. The four giant ones, whose orbits are outside that of Mars, are Jupiter, Saturn, Uranus, and Neptune. Between the orbit of Mars and Jupiter there exists a host of comparatively insignificant minor planets or Asteroids, each of which has its own appointed path round the same centre as the ones just mentioned. In this way, the inferior, the giant, and the minor planets trace a number of imaginary concentric circles round the sun. The course that each takes is not truly circular relatively to the sun; neither is the Sun the exact centre. It is convenient, however, and very nearly accurate, to consider each to be so, but it must be borne in mind that the Sun is a moving centre.

The Relative Proportions of the Earth.—The Earth is, then, the third in order from the Sun, and is about 93 millions of miles distant from it. The outer boundary of the System is defined by Neptune, whose orbit is 5,500 millions of miles in diameter. Our Planet is the largest of the four inferior ones. Jupiter is the largest of all. In round numbers, the Earth is 8,000 miles in diameter, Jupiter 80,000, and the Sun 800,000 miles. The diameter of Jupiter being ten times that of the earth, its volume is 1,000 times as great, so that, as the

Sun bears a similar ratio to Jupiter, as the latter does to the Earth, it would take one million earths to fill up a globe equal in volume to the Sun. The comparison with these greater orbs places the Earth in quite a humble position.

Compared with other units, on the other hand, the Earth has considerable dignity of its own. If we add the height of the loftiest mountain, to the depth of the deepest part of the ocean, we have a unit, compared with which the Earth excels in magnitude. The highest peak is 29,000 feet above the level of the sea. The greatest ocean depth rarely exceeds 28,000 feet. These together, make a total of nearly 11 miles, so that the greatest irregularity of the Earth's surface is a little more than $\frac{1}{750}$ part of its diameter. The most lofty mountain peak and the deepest part of the ocean are separated by a distance of 4,000 miles. The average gradient from one of these points to the other is not more than one in three hundred and sixty, or 1 inch in every 10 yards. This is the steepest average gradient, and is from the abyss eastward of Japan to Mt. Everest. In all other instances it is much less. The Earth has a comparatively smooth surface, and were it possible to make a globe 20 inches in diameter, with all the mountains and hollows accurately represented, it would feel quite smooth to the hand; and were sufficient water to correspond with the oceans placed upon it, it would be scarcely sufficient to damp a handkerchief. In all our thoughts concerning the structure of mountains, it is valuable and even essential to keep these facts in mind.

The Relative Motions of the Earth.—The great speed of the Earth's motion has also an important bearing upon certain changes which have taken place during its history, on account of the great stresses set up in the crust. During the daily rotation on its own axis, the equatorial periphery is constantly moving at a rate of rather more than 1,000 miles an hour, or about 1 mile every three and a half seconds.

In its yearly journey round the Sun, it travels 583 millions of miles, which is equivalent to a velocity of 18 miles every second. It would take an express train 1,000 years to travel the distance accomplished by the earth in one. 18 miles per second is 100 times greater than the speed of a rifle bullet. Such a velocity is startling in its swiftness, but is quite commensurate with so large a mass as the Earth is, compared with ordinary standards of measurements. It is scarcely more than a rifle bullet in size, compared with the immensity of space.

Extent of Land and Ocean Compared.—The Earth is an approximate spheroid, and if it were possible to look down upon it from the Moon or some distant point in space, the large extent of its water area would be very noticeable. The amount of land which is visible from beneath the ice of the Polar regions, and above the waters of the oceans, during one revolution, is only equal to about one-

quarter of the total area. The remaining three-quarters of the surface is hidden from view by the seas. Although the superficial area of the oceans is large, the volume of water is trifling in comparison with the solid portion of the Earth, which everywhere underlies it. The land surface contains slight depressions, over wide areas, in which the waters of the deep lie. The greatest depth of the ocean is a little over $5\frac{1}{4}$ miles. It has been computed to have an average depth of about 2 miles. The various estimates of the thickness of the crust of the Earth, have given it a total of from 14 to 75 miles.[1]

If we set out two circles, a 20-inch one to represent the outer and another the inner surface of the earth's crust, the 20-inch circle will correspond to a diameter of 8,000 miles; each inch will represent 400 miles. The second circle will be only $\frac{1}{8}$ of an inch within the other, if we take the solid crust to be uniformly 50 miles thick. Supposing the oceans to cover the whole of this land to a depth of 2 miles, this may be shown by another circle $\frac{1}{200}$ part of an inch outside the first one. The thickness of the line we draw will probably more than represent the whole of the water depth.

The oceans are, therefore, little more than a film spread over the outer surface of our planet. Within the outer shell, there is supposed to be another sea of molten matter, which from time to time makes itself felt in volcanic eruption. It is, however, the solid portion of the Earth, which constitutes its crust, that is now to engage our thoughts.

Stratified Rocks and Earth Disturbances.—The greater portion of this solid matter has been slowly accumulated at the bottom of the oceans. Layer upon layer, of sedimentary deposit, has been laid down and is still being laid down beneath the sea. The material which forms our highest mountain peaks was once lying in a horizontal position, and was probably covered over by other layers of similar deposit of great thickness. With the slow and continuous addition of layer to layer, the earth has grown appreciably in size, as the ages of its existence have rolled on. It will thus be seen that, as the stratified sediments were once lying prone in the ancient ocean bed, and are now upraised into lofty peaks, some disturbing forces have since come into play. More than this, since their elevation, they have been subjected to the long continued wearing action of the many atmospheric agencies. They have been termed "Monuments of Denudation." The materials removed from the uplands have been spread out to form new layers in the seas.

If the process of sedimentation had proceeded without interruption down to our own time the order of the layers from the lowest to the highest would be an indication of their relative age, the lowest being the oldest, and the uppermost the more recent. It would,

[1] K. von Zittel, *History of Geol. and Palæontology*, trans. by Maria M. O. Gordon, 1901, p. 177.

in that case, have been impossible to examine the lower strata so deep down in the crust. The disturbances have, therefore, made these lower deposits accessible to investigation, but at the same time, the determination of their relative age has been made more difficult, as in few places, if any, is the original order maintained. In no place is the continuous sequence of rocks found in unbroken succession. In fact, as age has succeeded age, and movement has succeeded deposition, the successive layers have generally become more and more local in their distribution.

The intricate problem of unravelling the history of the deposits which, after so prolonged an existence, have become hardened into rocks, is the work of the geologist. He has surveyed the systems of strata and collected specimens; carefully noting the place where each was obtained and the condition of the surrounding rocks, whether still horizontal or highly disturbed. He has submitted these specimens to careful microscopic and chemical examination, and brought all the powers of modern discovery to his aid in determining the story of each stone.

The long record of life, which has left its imprint within the rocks, is an invaluable guide to the determination of the order and

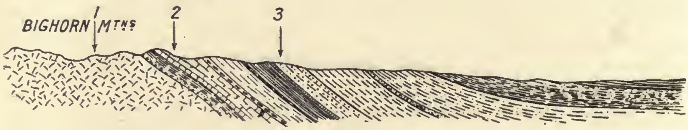


Fig. 1.—Stratified Rocks exposed by Upheaval and Denudation in the Rocky Mountain Region, Wyoming.—1, Granite; 2, Primary strata; 3, Secondary strata. (N. H. Darton, *U.S. Geol. Sur. Atlas folio* 141.)

age of many divisions. An almost unbroken chain of life has existed from ancient times down to the present. The crustaceans of the primæval waters, the fish which succeeded them, together with monster reptiles and mammals of later ages, as well as man, have all left memorials behind them, to serve the scientist's purpose. The information gathered in this way are tabulated, and the history of the locality in which each specimen was found, is made out, and so theories of the Earth's formation may be built up.

The Geological Rock Systems.—Much of the visible rock area of the Earth has come under observation; the original order of the successive layers of deposit has been unravelled; and names have been given to individual beds and groups of layers. The grouping of the various strata, with their order of superposition, is given in the following table. The names of the systems indicate the relative age of the deposits; those of the groups are mostly derived from the locality in which the beds were first surveyed. The latter

are themselves again subdivided into strata, layers, beds, and laminæ, which, in some cases, are quite thin.

Quaternary	Upper Boulder Drift, Pleistocene, Lower Boulder Till,	500 feet.
Tertiary	Pliocene,	350 ,,
	Miocene,	1,000 ,,
	Oligocene,	600 ,,
	Eocene,	5,000 ,,
Secondary	Cretaceous,	2,000 ,,
	Neocomian,	1,500 ,,
	Jurassic,	5,000 ,,
	Triassic,	2,500 ,,
Transition,	Permian,	1,500 ,,
Primary	Carboniferous,	12,000 ,,
	Devonian,	5,000 ,,
	Silurian,	5,000 ,,
	Ordovician,	7,000 ,,
	Cambrian,	10,000 ,,
Transition,	Keeweenawan,	30,000±,,
Pre-Cambrian	Upper Huronian,	8,000 ,,
	Middle Huronian,	10,000 ,,
	Lower Huronian,	10,000 ,,
Fundamental Complex	Upper Laurentian,	12,000 ,,
	Lower Laurentian,	30,000±,,

The depth of the various deposits is only intended as a guide. The thickness in many cases varies very considerably in different parts of the world. The Eocene, which in England only measures hundreds of feet in thickness, is more than 10,000 feet thick in parts of the American Continent and India. Again, it is impossible to define the depth of the very oldest rocks, as their lower surface has never been reached.

The four great systems, the pre-Cambrian, the Primary, Secondary, and Tertiary, have either been deposited beneath the ocean, or have at some time in the Earth's history been covered by the sea. They are included within the undoubtedly stratified, sedimentary rocks. The history and origin of the very lowest, as well as the Quaternary, which is the last system, are not so easily defined, and have caused much difference of opinion. They have been accounted for in many different ways by numerous observers who have investigated them. They will, in consequence, need fuller treatment than the remaining ones.

The Problem and Method of Interpretation.—The problem of

the earth's history is thus an exceedingly complicated one. It resembles Milton's body of truth, "Hewn in pieces and her limbs scattered over distant regions, her friends and disciples having to go wandering all over the world in quest of them." In piecing together the fragments of the story, there is a maxim which it is imperative to keep before us. It was first enunciated by Hutton, no doubt to counteract the extragavant dogmatic theories of his own and former times. He laid it down as an axiom of geological deduction, that every conclusion should be based upon observed and carefully enumerated data. No supernatural or unknown forces are resorted to. The events and changes of past epochs are explained by the phenomena of the present age. "In our investigations no powers are to be employed that are not natural to the globe, no action to be admitted, except those of which we know the principle." [1] "The fundamental principles, for which the Huttonian fought, have become the very life and soul of modern geology." In a few words, "The present, geologists tell us, contains the key to the past."

Other schools of thought have endeavoured to exceed the Huttonian maxim, and to affirm that we may not attribute to any cause which we employ to explain the phenomena of the past, a greater degree of efficiency than we see it to possess while at present in action. We may, however, be guided in this by so eminent an authority as Professor James Geikie, who says that, "although the work performed by geological agents of change has been the same in kind, it has necessarily varied in degree from time to time." [2] and Mr. Green, who also says that, "while we resolutely reject agencies differing in kind from those of the present day, we may allow a difference of degree." [3]

In our deductions we may not attribute a phenomenon to a cause of which we have no knowledge. We are, however, at liberty to reason from known causes producing minor effects, to similar causes, and attribute to them a greater degree in order to account for similar but greater effects which have been produced in the past.

The question of time must also be taken into account. If a minor cause, acting through unlimited eras, will explain certain effects, we should hesitate to say that the effects were the result of greater causes, acting for shorter periods. Legitimate deduction is thus confined within very definite limits.

[1] Sir A. Geikie, *Geological Sketches*, 1882, p. 293.
[2] J. Geikie, *Earth Sculpture*, 1898, p. 295.
[3] A. H. Green, *Geology for Students*, 1882, p. 696.

CHAPTER III.

SEDIMENTARY CYCLES.

Origin of Rocks: Two-fold Problem—Method of Determining the Origin of Primitive Rocks—Present Sedimentary Cycle—Colour and Chemical Composition of Oozes vary with Depth of Ocean—Three-fold Division of Cycles—Terrigenous Muds Contrasted with Ocean Oozes—Tertiary Sedimentary Cycle—Secondary Sedimentary Cycle—Chemical Composition of Chalk at various Depths—Jurassic and Permian Sedimentary Cycles.

The history of the most ancient granite rocks takes us back far into the unnumbered ages of antiquity. Their mode of origin is shrouded in mystery and jealously guarded. The opinion of geologists is somewhat divided regarding their formation, and although there is a tendency to consider them all to be altered sediments, the evidence in favour of this, so far deduced, has failed to convince many authorities.

Origin of Rocks: Two-fold Problem.—The stratified rocks have been derived, to a greater or less degree, by secondary erosion from the earlier rocks, so that every theory of rock generation must account for the very oldest or primitive rocks as distinct from the derivatives. This problem is a two-fold one. The first requirement is to determine how they came into being, and secondly, by what means they have assumed their crystalline and complex condition. The attempt to answer the first part of this problem will take the form of a comparison between the characteristic features of the plutonic rocks with those of the sedimentary rocks, whose origin is well known. In this way we are able to reason from the known to the obscure, and to prove with some degree of certainty the origin of these monuments of antiquity.

Method of Determining the Origin of Primitive Rocks.—The rocks of the earth's crust have been separated into systems by means of the evidence afforded by the effects of great physical changes which have taken place from time to time, as well as that contributed by the fauna and flora. The contrasts between the highly disturbed transitional rocks and those which compose the less disturbed systems, together with the fossil records, reveal the history of the rocks, but we have to turn to the resemblance between one system and another to ascertain the origin of the materials of which the

strata are composed. The determination of rock origin necessarily precedes the narration of earth history, and requires entirely separate treatment.

For this purpose it is necessary to select instances from the geological record where sedimentation has proceeded for long periods unchecked by secondary processes. The character of sediment formed during periods of deformation is quite different to those formed during epochs marked by freedom from disturbance. Deep accumulations of fragmental rocks have been locally brought together at such times; but, generally speaking, the more important systems were laid down during times of uninterrupted progress. It is only in such cases that a definite and useful comparison is observed. This analogy is to be seen in the chemical composition and three-fold divisions of the various groups of stratified rocks formed under similar circumstances in all ages of the earth's history. Every system where this condition is fulfilled, whether present or past, is divisible into three stages, upon a chemical and colour basis. They may be termed sedimentary cycles, and will be taken in order from the latest to the earliest.

Present Sedimentary Cycle.—The investigation of the ocean bed was exhaustively carried out during the voyage of the "Challenger." It was established beyond question that an intimate relationship exists between the depth of water and character of deposit. This is so constant that "it was found possible to predict with certainty the nature of the bottom as soon as the depth was ascertained."[1] Confined to the greatest depths of the ocean, and covering an area of 2,250,000 square miles, at an average depth of 3,000 fathoms, a siliceous deposit is forming which contains from 50 to 70 per cent. of silica. At an average depth of 2,000 fathoms, and covering 49,000,000 square miles, the ooze is composed very largely of carbonate of lime, to the extent of from 60 to 70 per cent. Between the siliceous deposit of the deep and the calcareous ooze of the shallower water, and at an average depth of 2,700 fathoms a somewhat different form of mud is being laid down, which covers an area of 51,000,000 square miles, and is known as the Red clay. It owes its colour to a high percentage of peroxide of iron and manganese, and contains on an average about 6 per cent. of carbonate of lime and 3 per cent. of siliceous matter, together with 85 per cent. of fine washings.

Colour and Chemical Composition of Oozes vary with Depth of Ocean.—The colour of these oozes also varies with the depth. Underlying the deepest deposits examined by the officers of the "Challenger" expedition, which are red, the ooze is pale yellow or straw colour. Passing from the pelagic areas towards shallower water, the colour varies from red to red-brown, chocolate, blue, and slate

[1] Sir J. Murray and Renard, *Challenger Reports, Deep Sea Deposits*, 1891, p. 279.

colour. Ascending through the clays to the calcareous levels, blue and grey predominate. When these upper clays are dried the high percentage of lime produces a whitish paste. There is, therefore, a gradation of colouring from the light straw, through the variegated zone to the uniform red, above which the tint varies again, and then culminates in the white ooze of the higher levels.

There is no arbitrary distinction between these three types of deposit, but a gradation from one to the other as the depth varies. This is more clearly shown by the following table, in which the average analysis of five samples at each average depth is set out. A small proportion of the less important chemicals, such as potash and soda, is omitted, as will be seen from the totals, but this does not in any way affect the relation between the chemical composition and depth of ocean, which is all that the figures are intended to show, and is of the utmost value in determining the origin of sediments. This should be carefully noted before passing on, and retained in the memory for comparison with subsequent tables of a similar nature :—

Relation of Chemical Compositions of Oozes to Depth of Ocean.

Average Depth.	SiO_2, Silica	Fe_2O_3, Ferric Oxide. Al_2O_3, Alumina. MnO, Manganese Oxide.	$CaCO_3$, Carb. of Lime. $MgCO_3$, Carb. of Magnesia.	Total.
Fathoms.	Per cent.	Per cent.	Per cent.	Per cent.
1,400	10·4	7·62	77·74	95·76
1,800	11·6	7·08	75·85	94·53
2,100	22·4	13·78	57·56	93·74
2,300	30·09	21·9	35·78	87·77
2,600	40·18	27·9	24·5	92·58
2,750	43·8	22·02	27·4	93·22
2,850	46·9	27·3	16·76	90·96
3,000	55·7	31·4	6·00	93·10

Challenger Reports, Deep Sea Deposits, Tables, pp. 198 and 219.

The percentage of silica increases, while the percentage of carbonate of lime decreases, with the depth. At 4,500 fathoms the remains of siliceous organisms make up 80 per cent. of the deposit, so that below 5,000 fathoms the deposits would probably consist of pure silica. At 500 fathoms the carbonate of lime amounts to over 90 per cent., and is practically pure carbonate of lime. It is probable that since the silica percentage rises so high in pelagic depths, the 30 per cent. of iron and alumina is about the maximum, and that it decreases above and below the 3,000 fathom line.

Three-fold Division of Cycles.—These deposits monopolise the greater part of the present ocean bed, and naturally fall into three

divisions. They are the straw-coloured siliceous oozes, the red oxides of iron, and the pink and white calcareous muds. The lowest deposits form the first stage in the evolution of the acidic quartzites which usually form the base of the ancient sedimentary systems. The red clays consist of silica, peroxide of iron and manganese, and alumina, besides all the rarer minerals.[1] The percentage of silica is low or in basic proportion in the clays, so that they are similar in composition to the slates, micas, and some sandstones which occur in abundance in the sedimentary rocks. The calcareous muds are represented in the ancient rocks by ultra-basic serpentine, peridotite, and the like, and in the younger systems by limestone. It is important to notice the order of deposition of the silica, iron, and lime, because the same order is often repeated in the older rock systems.

Terrigenous Muds Contrasted with Ocean Oozes.—There is a clear distinction between the muds composing this cycle and others which are accumulating in enclosed seas, such as the Mediterranean, and in the shallower water following continental margins. The Red and Blue Muds and Greensands in these positions are very complex in structure, and the materials are principally derived from the disintegration of the land. The Blue Muds are the most extensive, and contain as much as 63 per cent. of silica and 25 per cent. of carbonate of lime. The Greensand contains 30 and 47 per cent. of those respective chemicals. The silica consists principally of quartz particles which are relatively rare or absent in typical pelagic deposits. These terrigenous muds represent the intervention of secondary mechanical causes, and cannot be compared with the more abyssal oozes forming these cycles, and which are beyond the limits reached by the products of erosion. The distinction is quite definite, and as rocks formed under similar circumstances exist in all the older systems, it is necessary to compare like with like, in order to ascertain the origin of the primitive rocks. In subsequent chapters the ancient derivative rocks, in a measure comparable with terrigenous muds and beach deposits, will be considered, in which physical changes are recorded which make up the various chapters of the earth's history.

Tertiary Sedimentary Cycle.—Continental conditions generally prevailed over all the regions where Tertiary deposits have been preserved. Large inland lakes existed and great quantities of silt were washed into them from the highlands, so that it is difficult to discover localities where the hollows were deep enough and far enough removed from the effects of the erosion for the deposition of oceanic muds, but evidence is not lacking that in some localities complete systems were built up.

Above the sands, conglomerates and pebble beds, which mark a period of mechanical deposition at the opening of the Tertiary

[1] *Challenger Reports, Deep Sea Deposits,* 1891, p. 204.

era in America, calmer conditions prevailed, and several thousand feet of deposit were laid down in deep depressions. The lower Eocene consists of aluminous and uniformally siliceous, flinty sandstone, almost quartzite, or pink and white massive sandstones, marls, clays, and soft shales. They are followed by red, grey, yellow, green, and purple sands.[1] The colours are most beautifully variegated, from various shades of pink to brick red, but the red predominates. The upper Eocene is a widely distributed white limestone, which includes the Nummulite limestone of Florida.[2]

The Eocene of Sind is upwards of 10,000 feet in depth, and lies in the following order :—

Nummulite limestone.
Light brown limestone alternating with clays.
Ruby-coloured sandstones, shales, and clays with red and brown tints.

A similar succession is exposed in the Tirah and Bazar valleys of the Punjab. The basal member is a hard white quartzose sandstone with some pebbles derived from the underlying formation. It is overlain by brown needle shales, then shaly-limestone and red shales, above which is the Nummulite limestone again.[3]

In Northern Nigeria the order is :—

30 feet.	Soft chalky fossiliferous limestone (sometimes Nummulitic).
10 feet.	Calcareous clays.
190 feet.	Ferruginous clays, red, yellow, green, and black shales and clays.[4]

The Tertiary rocks of England, Belgium, and France vary from terrigenous to pelagic sediments. The base or lower Eocene consists of fine quartzose glauconitic green sandstone with green-coated flints, which rest directly upon the chalk, or of grey-bluish, brown and slate-coloured plastic clays of the London clay horizon. The middle Eocene is composed of variegated grey, brown, and red clays, and fine dark green quartzose sands, sometimes ferruginous. They pass up into the Calcaire Grossier,[5] of the Paris basin, and the Nummulite limestone of the Greater Mediterranean Sea. The minor basin of the Pyrenees occupied a depression in the chalk. The greensand covers a relatively small area, while the Calcaire Grossier of the shallower water is widely extended and overlaps the lower deposits, and itself rests upon the chalk, because of the

[1] W. Bulloch Clark, Correlation Papers, "Eocene." *Bull. U.S. Geol. Survey*, No. 83, 1891. p. 143, [2] *Ibid.*, 1891, p. 65.

[3] H. H. Hayden, "Geol. of Tirah and Bazar." *Geol. Survey India, Mem.*, vol. xxviii., 1899-1900, p. 101.

[4] Dr. J. D. Falconer, *Geol. of Northern Nigeria*, 1911, p. 168.

[5] A. de Lapparent, *Traité de Géologie*, 5th ed., 1906, p. 1497.

greater area covered by what we may term the calcareous contours. The three divisions of the Eocene are so distinct that M. Lapparent supposed that the basin was flooded after each was deposited in order to explain the formation of the next. The distinctions are, however, the same as are observed in the bed of the present seas, which shows that they are due to the difference in depth of the water within the basin, whose surface level remained about constant during the deposition of all the sediments.

The lower Miocene of France commences with a base of sandstone and conglomerate derived from the older rocks, which passes up into purplish and red marls, and red sandstone, like the Old Red Sandstone, and these into greenish and white foliated marls, usually calcareous, above which is the Indusial Limestone.[1]

Secondary Sedimentary Cycle.—The same principle is fulfilled in the rocks of the Secondary system. The pelagic depths of the ocean in which the English and French series was deposited stretched across the North Sea, from Yorkshire to Denmark. This was a typical Red Clay area, and was probably from two to three thousand fathoms in depth. In Norfolk, Lincolnshire, Yorkshire, Heligoland, and Westphalia the lower Cretaceous series is represented by the Red Chalk, which was "doubtless once continuous over this entire area," and consists of Red Clays, Red Marls, and Red sandy deposit. It is deep brick red in colour, and contains numerous quartz grains; above, it becomes dark red and then pink. The colour changes as it becomes more calcareous,[2] until it passes into the marly chalk, and finally, the white chalk. The differentiation is well illustrated on Plate I., in which the basal sandstone is overlain by ferruginous and then calcareous marls.

In the South of England the place of the Red Chalk is taken by the Selbornian or Gault and Upper Greensand. The former consists of terrigenous deposits, which, on account of exceptionally strong currents, were taken far out to sea. The Upper Greensand is similar to the deposit now forming on the margin of continental land between the terrigenous and calcareous deposits, so that the Selbornian indicates the last effects of a transgressing sea, which preceded the deposition of the Cretaceous series. Above these, again, are the chloritic marls of the lower chalk, which are hydrated silicates of manganese, alumina, and iron, and contain numerous grains of quartz, felspar, and mica. The quartz grains sometimes form 40 per cent. of the whole. This is followed by the middle and upper chalk. The variation in the chemical composition of the Chalk series at different horizon is the same as in the ocean oozes at the various depths, as will be seen by reference to the accompanying table, in which the $CaCO_3$ decreases with the depth and SiO_2 increases

[1] Sir C. Lyell, *Elements of Geology*, 6th ed., 1865, p. 222.

[2] A. J. Jukes Browne, "Cretaceous Rocks of Britain," vol. i., 1900, p. 303. *Mem. Geol. Survey Un. Kingdom.*

The Chalk Cliffs, Hunstanton.

towards lower levels. The series is thus a complete one, from the semi-pelagic Red Clays through the various grades to the White Chalk.

CHEMICAL COMPOSITION OF CHALK AT VARIOUS DEPTHS.

Horizon.	SiO_2, Silica.	Al_2O_3, Alumina. $FeO + Fe_2O_3$, Iron Oxides.	$CaCO_3$, Carb. of Lime $MgCO_3$. Do. Magnesia.	Total.	References.
	Per cent.	Per cent.	Per cent.	Per cent.	Vol. Page.
Upper chalk, .	·4	·6	99·0	100·0	III., 357
Middle ,, .	·6	·74	98·3	99·6	II., 526
,, ,, .	1·06	·59	97·7	99·3	II., 530
Lower, Pink chalk,	2·0	·5	96·4	98·9	II., 341
Yellow chalk, .	4·0	2·0	93·6	99·6	II., 341
Pink ,, .	4·49	3·5	92·5	100·5	I., 324
,, ,, .	5·16	2·3	91·8	99·2	I., 323
,, ,, .	7·4	1·7	89·1	98·2	I., 325
,, ,, .	7·37	1·83	88·4	97·6	I., 323
Hard grey chalk, .	5·2	3·13	87·4	95·7	II., 341
Lower chalk, .	9·37	1·94	85·94	97·2	II., 333
,, Pink chalk,	10·8	3·48	82·3	96·6	II., 341
Chalk marls, .	14·1	1·7	83·2	99·0	II., 336
,, ,, .	18·1	1·6	78·9	98·6	..
,, ,, .	19·4	2·1	77·2	98·7	..
,, ,, .	21·0	1·6	76·3	98·9	II., 325
Red chalk, .	18·0	4·99	75·5	98·6	I., 323
,, ,, .	16·6	5·6	73·7	95·9	I., 325
Lower chalk, .	23·5	2·2	71·9	97·6	II., 333
Chalk marls, .	24·6	2·3	71·5	98·4	II., 336
Lower chalk, .	25·76	3·3	70·4	99·4	II., 335
Chalk marls, .	26·2	1·7	70·0	97·9	II., 335
Red chalk, .	24·6	4·8	68·06	97·4	I., 326
Chalk marls, .	33·0	2·8	62·2	98·0	II., 336
Lower chalk, .	40·38	2·37	56·1	98·8	II., 335
Red ,, .	42·4	10·2	46·5	99·1	I., 326
,, ,, .	39·2	15·7	37·1	92·0	I., 325

In Algeria the base of the Cretaceous system "effects in general the pelagic muddy facies," and forms a geological sequence from four to five thousand feet in depth. Over 2,000 feet of sandstone, siliceous clays, and marls occasionally calcareous and schistose, lie beneath the Gault horizon, which consists of 1,000 feet of sandy green and mottled clays and siliceous limestone. They are followed by the Chalk marls and white Chalk as in England.

A more distinctly representative section of the Arabian coast is as follows :—

Upper Cretaceous Limestone.
Red and Variegated Marls.
Yellow and Brown Micaceous sandstone.[2]

[1] A. J. Jukes Browne, "Cretaceous Rocks of Britain," vols. i.-iii. *Mem. Geol. Survey of Un. Kingdom*, 1900-1908.

[2] E. Suess, *Face of the Earth*, vol. i., p. 365.

The same features are reproduced in the Cretaceous rocks of Palestine. The Nubian sandstone consists of bright and dark red, purple and brown, soft sandstone with a conglomerate at the base. It is remarkably uniform in lithological composition, and is practically made up of fine sandy grains, which owe their colouring to stains of oxide of iron and manganese.[1] Surmounting the Nubian rocks is a great depth of hard grey, yellowish and soft white limestone. The richness of the colouring displayed by the alternating yellow, orange, red, and purple tints is difficult to adequately describe.[2]

The Cretaceous rocks are also well exposed in Afghanistan and Russian Turkestan, where the effects of a transgression of the ocean between the Jura-Cretaceous is clearly seen in the change in the character of rock. The entire sequence measures from four to six thousand feet in depth.

Cretaceous,	Coral limestone, light grey. Clayey shales with frequent beds of limestone.
Pelagic Seas,	Quartzose sandstone, fine-grained and even-bedded, with occasional calcareous beds.
Deepening Sea,	Coarse brown sandstone and grits.
Upper Jura,	Irregular beds of limestone, sandstone, and ferruginous shales. Marly shales of even texture.[3]

Red and green, micaceous sandstone, ferruginous sands, marls, and clays and limestone are typical of the Turkestan Cretaceous, which is of great depth.[4]

Similar conditions of deposition are recorded by these rocks of this age in Texas[5] :—

Austin Chalk.
Dark blue shale with calcareous concretions.
Sandy clays.
Sandy and ferruginous clays weathering into siliceous hæmatite.

[1] W. F. Hume, *Geol. of Peninsula of Sinai*, 1906, p. 152.

[2] Prof. E. Hull, *Geol. of Arabia, Palestine, etc.*, 1886, p. 54.

[3] C. L. Griesbach, "Geol. of the Takht-i-Suleman." *Records Geol. Surv. of India*, vol. xvii., part 4, 1884, pp. 184, 185.

[4] C. L. Griesbach, "Geol. of Russian Turkestan." *Records Geol. Surv. of India*, vol. xx., part 3, 1887, p. 125.

[5] R. T. Hill, "Geol. of Parts of Texas." *Bull. Geol. Soc. Am.*, vol. i., 1894, p. 305.

And in South America[1] :—

Yellow, blue, and grey chalk.
Grey and red marls.
Schistose green and cerise-coloured marls.
White and red crystalline siliceous conglomerate.

Jurassic and Permian Sedimentary Cycles.—Shallow water and land conditions prevailed very generally during these periods, so that sedimentation of the mechanical type was characteristic of them, but, at the same time, there is evidence that cyclic systems were being built up in some parts of the ocean bed. The Trias and Lower Jurassic of the Punjab ranges consist of a great depth of bright red grits and shales, arenaceous and red shales, and pure limestone aggregating some two to three thousand feet, or cherty sandstone, shale, and slaty beds with blue earthy limestone, and, finally, dolomite limestone.[2] Below this again is yet another cycle consisting of quartzites and micaceous sandstone, shale and slate, and massive dark blue limestone and dolomite, which commenced to be formed after a transgression of the sea at the close of the Primary epoch, and is known as the Kuling system in India.[3] The calcareous ingredient gradually increases upwards in the shale beds beneath the limestone.[4]

The Trias of Central Europe grades upwards from tinted crystalline sandstones and shales to red and brown quartzose schists into the Muschelkalk.[5] The Permian of Kansas and Texas consists of from two to five thousand feet of sandstone beneath and limestone above.[6]

[1] Dr. C. v. Burchhardt, *Profils géologiques de la Cordillère Argentine-Chilienne*, 1900, p. 90.

[2] R. Lydekker, "Geol. of Kashmer and Chambra," *G. S. India, Mem.*, vol. xxii., 1885, pp. 139-144; H. H. Hayden, *G. S. India, Mem.*, vol. xxviii., part 1, 1898, p. 105.

[3] R. Lydekker, *l.c.*, pp. 144-185.

[4] Col. S. G. Burrand and H. H. Hayden, *Geog. and Geology of Himalaya Mts. and Tibet*. 1907-8, p. 235.

[5] H. Credner, *Traité de Géologie*, 1879, p. 466.

[6] W. B. Scott, *Introduction to Geology*, 1897, p. 430.

CHAPTER IV.

SEDIMENTARY CYCLES—*Continued.*

The Primary Sedimentary Cycles—Cambro-Ordovician Cycle and Type Section—Siluro-Devonian Cycle—Carboniferous Cycle—The pre-Cambrian Terrains—Basal Sandstones and other Sandstones Contrasted—Clastic Structure in Pelagic Sediments—Pre-Cambrian Sedimentary Cycles—The Cuddapah Series of India—The pre-Cambrian in China—The Huronian Series of the United States—The Grenville Series in Canada—Chemical Analyses of pre-Cambrian Rocks—Laurentian Sedimentary Cycle—Alternative Cycle Discussed.

In order to investigate the mode of origin of the most ancient rocks, it is necessary to ascertain whether the cyclic principle is applicable to the older sedimentary systems. The series so far considered, being only semi-indurated, have proved an easy prey to the repeated forces of denudation. Those now to be discussed are more capable of resisting such forces, so that, although so ancient and often much deformed, the original order of deposition is even more clearly indicated than in the more recent ones. Passing even deeper; from the oldest sediments to the region of the igneous rocks, the original character has been entirely lost, but owing to the fundamental nature of the minerals composing them, and although they have been melted, it is possible to trace a definite relation between the sedimentary cycles and the differentiation of an igneous magma.

The Primary Sedimentary Cycles.—The order of deposition of the strata composing the Primary system varies in different parts of the world. The Grand Cañon series is made up of one cycle only from the base to high up in the Carboniferous. In the Mississippi Basin there are three or four restricted or partial cycles, which were laid down during the same period. Movements of the ocean bed during sedimentation, either in an upward or downward direction, will account for this variation, as will be seen later. For the present purpose, the system is very generally divisible into three sections, as follows :—

1. The Carboniferous.
2. The Siluro-Devonian.
3. The Cambro-Ordovician.

The development of these three sections, one above the other, in the Rocky Mountains of Utah, where some 18,000 feet of stratified rocks have been exposed by upheaval and denudation, will be taken as a type, and those of other localities compared with them. The base of the topmost cycle is known as the Weber Quartzite, which is overlain by argillaceous schists, and these again by drab limestones, altogether about 7,000 feet in depth. The intermediate cycle commences with the Ogden Quartzite, pure white or grey in colour, and passes through olive-coloured clay stones and impure limestone, to the Wasatch Limestone, totalling about the same depth as the previous series. The Cambro-Ordovician sequence consists of about 3,500 feet of similarly arranged rocks. The basal quartzites are massive in proportions, and salmon, pink, white, or cream coloured, then come several hundred feet of sandy and mica-bearing schist or green argillites, which are overlain by siliceous limestone or calcareous shales. The concluding rock is the Ute Limestone, 1,000 feet in depth.[1] Similar conditions of sedimentation were in progress throughout the Primary ages in the Himalaya region of India and Tibet. Cambrian, Silurian, and Carboniferous Muth quartzites are each followed by shales, siliceous limestone, and then massive limestone, all of which are widely distributed.[2]

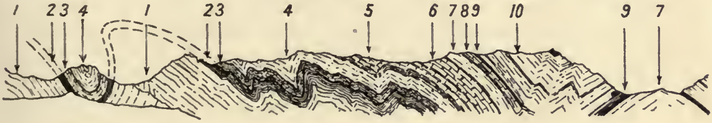


Fig. 2.—Section, 15 miles in length, to illustrate the alternation of Quartzites, Slates, and Limestones in the E. Central Himalayas.—1, Conglomerates, slates, and quartzite. 2, Bright Red Shales. 3, Limestone. 4, Flesh-coloured Quartzites. 5, Limestone and shale. 6, Coral Limestone. 7, Muth Quartzite. 8, Flaggy limestone. 9, Permian. 10, Trias and Rhætic. (C. L. Griesbach, *Mem. Geol. Sur. India*, vol. xi.)

The changes from the limestone of one system to the quartzite of the next, in each case, indicate the grand oceanic transgressions which are recorded by quite different phenomena in other parts of the world. They will be referred to again in later chapters.

Cambro-Ordovician Cycle and Type Section.—The Cambro-Ordovician cycle preserves the original order most clearly, and is traceable in many widely separated parts of the world. The rocks of this age in the north-west Highlands of Scotland are a convenient standard unit for comparison with the more ancient rocks to be described in the next chapter, since it is in complete agreement

[1] S. F. Emmons and A. Hague. *Geol. Exploration of Fortieth Parallel,* 1877, pp. 157-171.

[2] C. L. Griesbach, "The Sequence of Formation in Spiti." *Records G. S. India*, vol. xxii., part 3, 1889, pp. 160-163. Col. S. G. Burrard, R.E., and H. H. Hayden, *Geog. and Geol. of Himalaya Mts. and Tibet,* 1907-8, p. 233.

with the sediments of the present ocean. The basal conglomerates and flaggy grits which are partially of fragmental origin pass up into a fine-grained pink and whitish-yellow, piped quartzite and fine white siliceous sand, then follow red grits, shales, and mudstones, which are sometimes ferruginous or dolomitic, sandy dolomites, and finally cherty, mottled, and massive dolomites.[1] The whole series amounts to about 2,000 feet in depth. The pink and white quartzites, ferruginous shales and dolomite limestone correspond with the siliceous oozes, red clays, and calcareous muds of the ocean bottom, and, therefore, represent a typical cycle. The lowest Primary rocks of the southern Uplands of Scotland have other features in common with recent oozes, although they are somewhat different to the northern rocks. Radiolarian cherts take the place of the quartzites, and are followed by micaceous shale and slates and barren mudstones with ironstone and manganese nodules, higher up in the series nodules and ribs of limestone appear in the mudstones. These develop into lenticular masses as the Stinclair limestone [2] is approached, which was probably at the time of its formation, much more widely distributed.

The Stiper Stones form the local base of this cycle in Shropshire, which may be generalised as follows for Cambria :—

Llandovery, Llandeilo, and Bala limestones.
Llandeilo schists and flags, Caradoc sandstone, which are striped with impure limestone.
Lingula flags and micaceous shales with little lime.
Stiper Stones, thick yellowish siliceous sandstones, and crystalline quartz.[3]

These basal sandstones and quartzites form a distinctive geological horizon over practically the whole of the North American Continent. It has been traced in Colorado, Utah, the Mississippi Valley, almost all of the Eastern States, from Georgia and Alabama in the south to Vermont in the north, as well as in many parts of Canada.[4] In the majority of these districts a complete sequence

[1] B. N. Peach and Associates, "The Geol. Structure of the North-West Highlands of Scotland." *Mem. Geol. Survey, Un. Kingdom*, 1907, pp. 365, 407, 418.

[2] B. N. Peach and J. Horne, "Silurian Rocks of Britain," vol. i., 1899, pp. 46-51. *Mem. Geol. Survey, U.K.*

[3] Sir R. I. Murchison, *Siluria*, 1867, pp. 41, 54, 66.

[4] F. B. Weeks, "The Stratigraphy of the Uinta Range." *Bull. Geol. Soc. America*, vol. xviii., 1907, p. 435. W. O. Crosby, "The Archæan-Cambrian Contact near Manitou, Colorado." *Bull. Geol. Soc. Am.*, vol. x., 1899, p. 143. F. D. Adams and A. E. Barlow, "Geol. of the Haliburton and Bancroft Areas, Ontario." *Mem. Geol. Survey, Canada*, vol. vi., 1910, p. 341. W. G. Wilson, "Geol. of Nipigon Basin, Ontario." *Mem. Geol. Survey, Canada*, vol. i., 1910, p. 10. M. R. Campbell, "Palæozoic Overlaps in Montgomery and Pulaski Counties, Virginia." *Bull. Geol. Soc. Am.*, vol. v., 1894, pp. 175-6. C. W. Hayes, "Geol. of a Portion of the Coosa Valley in Georgia and Alabama." *Bull. Geol. Soc. Am.*, vol. v., 1894, p. 468. A. P. Low, "Exploration of the East Coast of Hudson Bay." *Geol. Sur. Canada, Ann. Rep.*, n.s., vol. xiii., 1900, p. 80D.

of beds is preserved, from the abyssal quartzites, through shales to massive limestones or dolomites, which vary in depth from three to four thousand feet. A section in Pennsylvania is representative, and exceeds 6,000 feet in depth. The lower quartzites are flesh red, wine yellow, or beautifully white, fine-grained and heavily bedded, and sometimes contain slaty bands. The Primal slate series, which follows, consists of red shales, chloritic slates, and hæmatite beds, which grade upwards into cherty siliceous limestone, which becomes less and less siliceous, until the pure limestone is reached. The chemical analysis of these rocks clearly reveals the gradational passage from the highly siliceous to the highly calcareous stage.[1]

VARIATION IN CHEMICAL COMPOSITION OF CAMBRO-ORDOVICIAN ROCKS.

Insoluble Residue mainly SiO_2.	Al_2O_3, Alumina. Fe_2O_3, Iron Oxide.	$CaCO_3$, Carbonate of Lime.	Total.
Per cent.	Per cent.	Per cent.	Per cent.
5·6	not recorded	93	98·6
4·8	,,	85	89·8
9·8	,,	53	62·8
26·4	,,	41·5	67·9
37·6	,,	48·0	85·6
46·1	2·5	39·9	88·5
SiO_2, Silica.	Al_2O_3, Alumina. Fe_2O_3, Iron Oxide.	CaO, Lime. MgO, Magnesia.	Total.
Per cent.	Per cent.	Per cent.	Per cent.
56·35	22·8	1·59	80·7
58·97	22·6	·23	81·8
87·8	9·0	·2	97·0[2]
97·0	2·6	·3	99·4[1]

Note.—Most of these analyses are in their correct stratigraphical relationships. The headings are repeated because of the absence of carbon dioxide, CO_2, in the last four samples. This may be accounted for by subterranean thermal changes.

The purity of these massive basal quartzites and sandstones has occasioned some surprise, and their origin has been the subject of considerable discussion, but this will be deferred to a later chapter.

The Cambro-Ordovician series is also widely distributed in China and India, where it closely resembles those already described. It has been recorded in the provinces of Chi-li, Shan-si, and in the

[1] J. P. Lesley, *Summ. Descrip. Geol. Pa.*, vol. i., 1892, pp. 170, 172, 300.

[2] F. Bascom, "Piedmont District of Pa." *Bull. Geol. Soc. Am.*, vol. xvi., 1905, pp. 297, 299.

Yang-tse river gorges. It sometimes amounts to 4,000 feet in thickness, and may be generally described in the following manner. Their great depth may be gathered from the illustration (Plate V.):—

Massive limestone.
Oolite and grey limestone.
Slaty and earthy limestone and shales.
Red and green shales.
Soft white and yellow clay of fine texture and pure white quartzite sands.[1]

The Purple Sandstone group of India overlies brilliant scarlet-coloured marls, and consists of red clays, uniform purplish marls becoming paler above. They are followed by dark micaceous shales, and these again by a dolomite formation, the whole measuring from 1,000 to 1,500 feet in thickness.[2] Or, again, quartzites and slates, red quartz shales, and coral limestone, 3,000 to 4,000 feet in depth.[3]

Siluro-Devonian Cycle.—On account of volcanic activity in North Wales and New Brunswick, which was accompanied by earth movements and transgression of the ocean, another cycle was commenced in Great Britain, the United States of America, and Canada. Similar processes of sedimentation proceeded throughout Upper Silurian and Lower Devonian times. It is known as the Clinton and Niagara group of Canada and the United States, and the Wenlock and Ludlow group of Great Britain. The proximity of volcanoes has locally modified the character of the sediments, but beyond their influence many sections, averaging 1,200 feet of strata, might be described in Pennsylvania, New York, Ontario, and New Brunswick,[4] in the same way as the earlier ones. Lava flows were repeatedly poured out during the deposition of the limestone member in Nova Scotia, but, in spite of this, the percentage of carbonate of lime increases towards the close of the cycle.

The Pennsylvanian series is an important one, and somewhat

[1] Eliot Blackwelder, *Research in China*, vol. i., part 1, 1907, pp. 25, 140, 267, etc.

[2] A. B. Wynne, "Geol. of Salt Range in the Punjab." *Geol. Survey India, Mem.*, vol. xiv., 1878, pp. 70-90.

[3] C. L. Greisbach, "The Sequence of Formation in Spiti." *Record Geol. Survey India*, vol. xxii., part 3, p. 160.

[4] A. C. Lane, "Notes on the Geol. Section of Michigan." *Am. Journ. of Geol.*, vol. xviii., 1910, p. 395. C. S. Prosser, "The Devonian and Silurian Rocks of New York." *Bull. Geol. Soc. Am.*, vol. iv., 1893, p. 100. H. P. H. Brumell, "The Geol. of Natural Gas and Petroleum in S.W. Ontario." *Bull. Geol. Soc. Am.*, vol. iv., 1893, p. 237. Sir J. W. Dawson, *Acadian Geology*, 4th ed., 1891, pp. 567-9, 578.

complete analyses of the various horizons have been made. The description [1] and composition [2] is as follows :—

Massive limestone, ...	600 feet.
Slaty limestone, ...	300 ,,
Red shales and fossil iron ore, . . .	800 ,,
Green, yellow, and grey clay shales, . .	650 ,,
	2,360 ,,

RELATION OF CHEMICAL COMPOSITION TO DEPTH OF SILURO-DEVONIAN SEDIMENTARY STRATA.

	Insoluble Residue 85 °/₀ SiO_2, Silica.	Al_2O_3, Alumina. Oxide of Iron.	$CaCO_3$, Carb. of Lime $MgCO_3$, Do. Magnesia.	Total.
	Per cent.	Per cent.	Per cent.	Per cent.
Limestone, . . .	3·7	·77	95·31	99·7
	9·15	1·39	90·2	100·7
Limestone, base, . .	20·24	2·93	76·07	99·2
Calc. shales, . . .	17·20	6·40	75·48	98·0
	31·44	11·06	52·45	94·9
	42·95	16·27	32·97	92·2
Red shales, . . .	58·24	28·14	3·1	89·4

The analysed samples were not taken from a vertical sequence of strata, but from typical beds in neighbouring parts of the same State, and were selected in such a manner as to render the table strictly comparable with the analyses of the recent oozes.

Carboniferous Cycle.—At the close of the Siluro-Devonian epoch volcanic action produced differential motion in the ocean bed, so that, as in Eastern North America, more land was exposed, while deep depressions were effected further West. It was within pelagic basins such as this that the Carboniferous cycle was laid down there, and in Europe and in other parts.[3] An important group of stratified rocks, 10,000 feet in depth, in Rhenish Provinces and Belgium, is representative. The base consists of quartzose sandstones and slaty schists, almost free from limestone, then follow in the usual order more schists and sands, iron ores with lenticular limestone bands, calcareous shales, and red limestone, and, finally, the massive Carboniferous Limestone.[4]

[1] J. P. Lesley, *Summ. Descrip. Geol. Pa.*, vol. ii., 1892, p. 802.

[2] J. C. White, " The Geol. of Pike and Monroe Counties. *Second Survey Pa.*, G 6, 1882, pp. 142-7.

[3] F. B. Weeks, " The Stratigraphy of the Uinta Range." *Bull. Geol. Soc. Am.*, vol. xviii., 1907, p. 435. A. Strahan and W. Gibson. " Geol. of South Wales Coal Field." *Mem. Geol. Survey, Eng. and Wales*, No. 231, 1904.

[4] Sir R. I. Murchison, *Siluria*, 1867, pp. 394-401.

E. F. H. Kayser, *Text-book of Comparative Geology*, trans. by P. Lake, 1893, pp. 92-98.

The Pre-Cambrian Terrains.—Below the base of the Primary system and between it and the igneous basement rocks there occurs a deep series or succession of strata in Europe, Asia, and America, which in many respects resemble those above them, but are unlike them in being almost totally lacking in fossils. They are often highly disturbed, crumpled, and distorted, and have even been melted, but, at the same time, in many places their original order has been preserved, and they sometimes lie almost in the original horizontality. Their proportions are often so profound that the strata so far described pale into insignificance before them.

Basal Quartzites and other Sandstones Contrasted.—The clear distinction between the peculiar type of sedimentation now being described and that produced by long-continued mechanical denudation is very marked in these ancient rocks. The difference is perhaps more striking than at any other part of the geological record. On the one hand, we have great developments of those massive pure quartzites and limestones with the intermediate clays and shales, and on the other even greater accumulations of fragmental sandstones and conglomerates, bearing clear evidence of the destructive agencies which brought them together. The Camp Creek sandstones of Montana [1] and the Torridonian sandstones of Scotland are from 11,000 to 16,000 feet in depth, but have scarcely a single feature in common with the sedimentary and differentiated cycles formed before and after them. They are transition rocks, and occupy strictly local positions between the Huronian and Primary systems.

Indurated sandstone of this class is sometimes called quartzite, but the distinction between it and those which so frequently occur in the Primary system, and again in the Huronian, has been pointed out.[2] The pure, white, and waxy basal quartzites are of distinctly different origin to the coarse fragmental variety. The former are usually attributed to subaerial or beach conditions of deposition, but their position always at the base of each system, their purity and relation to the pelagic oozes of the present ocean are here taken to be the true indications of their origin.

Clastic Structure in Pelagic Sediments.—The quartzites of the pre-Cambrian rocks, it is true, are sometimes ripple-marked and even fragmental and conglomeratic. The angular and sub-angular fragments composing the conglomerate are, however, usually of the same composition as the matrix in which they are embedded, and are thus an indication of infra-formational origin. The recently deposited and indurated sands were disturbed by crustal movement. The submarine currents caused by these movements then rolled and re-assorted them, after which they were again cemented

[1] C. D. Walcott, "Algonkian Formation of N.W. Montana." *Bull. Geol. Soc. Am.*, vol. xvii., 1906, p. 7.

[2] W. King, "The Kadapah and Karnúl Formation in Madras." *Geol. Survey India, Mem.*, vol. viii., 1872, p. 37.

together by a further supply of the silica which had built up the original quartz. By the same or a modification of the same process, shales of apparently fragmental origin may be produced from non-fragmental marls, and may be indistinguishable from shore silts in chemical and microscopic composition. It is thus evident that clastic shales, sandstones, and some pebbly conglomerates and cross-bedded quartzites are not so certainly of shallow water origin as has hitherto been believed to be the case.

Pre-Cambrian Sedimentary Cycles.—There are three or four, or even fewer, sedimentary divisions in the pre-Cambrian series, according to the locality in which it is situated, and as in the Primary system, this variation is, no doubt, due to crustal disturbances accompanying volcanic activity, since igneous rocks are frequently interstratified with them, and more especially in the upper divisions. The local disappearance of one or more sections may be due to absorption from beneath or to superficial denudation, so that the greater number is probably original.

Cuddapah Series of India.—It is convenient to select the Indian sequence as a typical development of the pre-Cambrian sequence, and compare the American and European with it. These old rocks are somewhat extensively distributed and exposed in the Peninsula,[1]

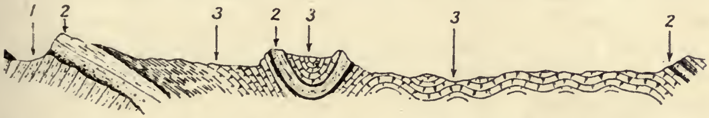


Fig. 3.—Section illustrating Relations of Pre-Cambrian Rocks in South Maharatta.—1, Gneiss. 2, Quartzite. 3, Siliceous Limestone. (R. Bruce Foote, *Mem. Geol. Sur. India*, vol. xii.)

and four complete or almost complete cycles, aggregating from 12,000 to 20,000 feet of stratified rock, with associated volcanics are recorded. The systems average from three to four thousand feet each, and are separated from one another and from the basement complex by beds of conglomerate, which are omitted in the following descriptive table. The complete series is known as the Kadapah system :—

Limestone.
Red sandy and talcose shales.
Very compact, grey, white, and buff waxy quartzite.

Siliceous and micaceous limestone.
Red and purple sandy and micaceous slates.
Mica schists.
Drab and white waxy quartzites.

[1] Leigh Fermor, "Report 11th International Geol. Congress." *Geol. Survey India, Record*, vol. xli., 1911, p. 291

Siliceous limestone.
Red earthy and slaty shales.
Reddish and grey grits, sands, and jasper.
Ripple-marked quartzites.

Cherty limestones and shales.
Ferruginous red sandstone and shales.
Hard purple slates.
Massive, purple, and hard false-bedded quartzites.[1]

The rocks of series number three become more calcareous towards the upper limits, and more siliceous and cherty towards the base,[2] which is probably true of the others, but is not recorded. The jasper rock is of the following chemical composition :—

	SiO_2, Silica.	Al_2O_3, Alumina. FeO, Fe_2O_3, Oxide of Iron.	CaO, Lime.	Total.
	Per cent.	Per cent.	Per cent.	Per cent.
Jasper, . .	97·2	2·25	·8	100·25

The Pre-Cambrian in China.—The pre-Cambrian series of China comprises three distinct systems, aggregating about 20,000 feet, and thus about equal in depth to the Indian. The lowest one is apparently an incomplete or truncated cycle, as the limestone is missing and the rocks are generally more quartzose than in previously-quoted instances. The felspathic and siliceous quartzites of the Wu-tai grade through pink micaceous quartzites into massive mica-schists, which contain a proportion of lime in the form of garnets. This is followed by the basal quartzite, slaty schists and phyllites, thick massive amphibolite schist, ferro-magnesian and garnet schists, and white marble, with the concluding siliceous and ferruginous limestones, together forming the Nan-tai system. Then comes a mass of transitional coarse sandstone and conglomerate, containing fragments of the previous rocks. Above them is the Hu-to or Ta-yang system, consisting of the usual dark grey and purple quartzites and sandstone, slates, argillites, flinty and impure limestones,[3] or the massive limestone which is widely distributed in North China.

Huronian Series of the United States.—The lower, middle, and upper Huronian systems of the region of the great lakes of North America have been worked out in great detail, and are now capable of being summarised in the following manner :—

The upper and middle divisions are often very similar lithologically, and consist of quartzites, slates, iron formation, and

[1] W. King, "The Kadapah and Karnúl Formations in Madras." *Geol. Sur. India, Mem.*, vol. viii., 1872, pp. 161-258, 296.

[2] W. King, *Ibid.*, vol. viii., 1872, pp. 188, 189.

[3] Bailey Willis and E. Blackwelder. *Research in China*, vol. i., part 1, 1907, pp. 114-129.

cherty carbonates from 2,000 to 3,000 feet in depth. The carbonates are believed to represent altered ferruginous limestone, but the bulk of the limestone was probably removed by the profound erosion which intervened between the deposition of the systems or at the conclusion of pre-Cambrian times. Each cycle has thus been truncated so that fragments of dolomite frequently compose part of the conglomerate at the base of the overlying quartzite. Not infrequently, as shown by the following section of the Animikie or upper Huronian, the sequence has remained almost intact.

Lake Superior[1]—

Ferric Dolomites.
Cherty iron carbonates.
Ferric slates and Cherts.
Quartzite stained with iron.
Quartzite, vitreous.
Claystone and Greywacke.

The mid Huronian of Michigan and Wisconsin is made up of 2,300 feet of quartzites, slates, and greywackes, iron-formation of

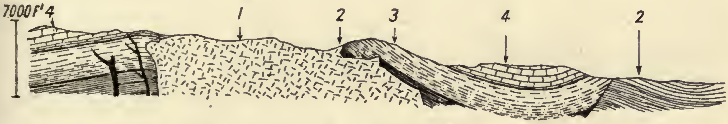


Fig. 4.—Section, 5 miles in length, showing Relation of Pre-Cambrian Rocks in Montana.—1, Granite. 2, Siliceous and arenaceous shales, with deep dark red and purple layers. 3, Finely laminated, soft green, grey and buff, limy shales. 4, Helena Limestone. (J. Barrel, *U.S. Geol. Sur. Prof. Pap.*, 57.)

considerable depth, and cherty iron carbonates again, or as in another section, quartz-slate, indurated sandstone, and red shales, which are overlain by red jasperites, red hæmatite, and, finally, iron carbonates, which are also believed to be altered calcareous rocks.[2] These systems form precipitous escarpments in the Rocky Mountain region of Montana. Single systems have been described from 5,000 to 12,000 feet in depth. Eight thousand feet of fine-grained compact quartzite, grey sandstone, purple quartzose sandstone, is followed by 4,000 feet of siliceous limestone, and then thin-bedded and massive limestone.[3] The upper beds become more

[1] C. R. van Hise and C. K. Leith, "The Geol. of the Lake Superior Region." *U.S. Geol. Survey, Mem.*, vol. lii., 1911, pp. 229-231, etc.

[2] A. Irving and C. R. van Hise, "The Penokee Iron-bearing Series of Michigan and Wisconsin." *U.S. Geol. Survey, Ann. Rep.*, vol. x., pt. 1, 1888-9, p. 380.

[3] C. D. Walcott, "The Algonkian Formations of N.W. Montana." *Bull. Geol. Soc. Am.*, vol. xvii., 1906, p. 7.

calcareous and the lower more siliceous.[1] The concluding limestones of the Lewis and Livingstone Ranges are cherty and magnesian, and more ferruginous, and then more siliceous towards their base.[2]

The following sequence[3] probably represents the upper and mid Huronian in this part of the Continent :—

Helena limestone, ...	2,400 feet.
Deep red siliceous and sandy shales, . .	2,000 ,,
Quartzites and buff sandy shales, . .	3,000 ,,
Newland Limestone, ...	2,000 ,,
Siliceous and sandy shales, . . .	1,500 ,,
Fine grained and reddish mica shales, .	300 ,,
Pink and grey quartz, micaceous, . .	400 ,,

Around Lake Superior, the major part of the lower Huronian formation consists of massive quartzite, very compact and vitreous, containing 98 per cent. of silica. It is usually white, but here and there it is tinted with some shade of pink or green. In the upper part the cement between the grains is locally calcareous. The calcareous constituent increases in quantity as the dolomite is approached, until the rock becomes a calcareous quartzite, and then finally siliceous dolomite.[4] The quartzite, argillaceous shale, and

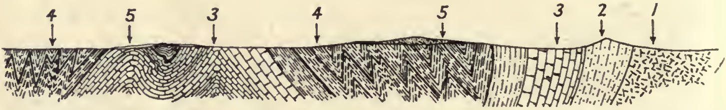


Fig. 5.—General Section across Band of Huronian Rocks infolded in Complex of Michigan. 3½ miles.—1, Granite. 2, Sturgeon Quartzite. 3, Radville Dolomite. 4, Clay slate and calcareous shales. 5, Cambrian. (C. R. van Hise and W. S. Bayley. *U.S. Geol. Sur. Atlas, folio* No. 62.)

dolomite aggregate from 2,000 to 2,400 feet in depth. The above is in the Lake Superior region ; further West, in the Ottawa district, reddish-grey gneiss grades up into well-stratified gneiss, reddish and grey in colour, along with which some limestone beds are interlaminated. These first appear as thin bands interstratified with the gneiss, but, on ascending, the gneiss becomes less and less until the rock becomes a regular crystalline limestone.[5]

The pre-Cambrian series of America, India, China, and Finland may be described as an alternating succession of quartzites, slates,

[1] *Ibid.*, p. 12.

[2] Bailey Willis, " Stratigraphy and Structure of the Lewis and Livingstone Ranges of Montana." *Ibid.*, vol. xiii., 1902, p. 321.

[3] C. D. Walcott, " Pre-Cambrian Fossiliferous Formations." *Ibid.*, vol. x., 1899, p. 206.

[4] C. R. van Hise and C. K. Leith, " The Geol. of the Lake Superior Region." *U.S. Geol. Survey, Mono.*, vol. lii., 1911, p. 332.

[5] R. W. Ells, " The Laurentian of the Ottawa District." *Bull. Geol. Soc. Am.*, vol. iv., 1893, p. 359.

and limestones with intervening conglomerates. Such a description is equally applicable to them in Arizona, Montana, Texas, the Lake Region, Newfoundland, and parts of Canada. The original Huronian sequence worked out by Logan and Hunt included four such systems, together measuring 17,500 feet in thickness.[1]

The Grenville Series in Canada.—By far the grandest exposure of these rocks has, however, yet to be described. They crop out from beneath the Primary cover and overlie the granite complex of Ontario, and are locally known as the Grenville series. There are several alternations of acid sedimentary gneiss of clay slate composition containing 79 per cent. of silica; basic amphibolites with 45 per cent. silica, 30 per cent. oxides of iron and alumina, and 18 per cent. lime and magnesia; and massive limestones.

All three classes of rocks are frequently interstratified and make up an immense series of sediments aggregating many thousands of feet in depth. When measured across the true bedding, the thickness amounts to 94,000 feet without any evidence of folding. Even if this does exist, it would still be by far the greatest development of pre-Cambrian sediments in North America, if not in the whole world. It is dominantly a limestone formation, but there is evidence that it may be divisible into sections like those already described. In one locality, 6,700 feet of limestone overlies 5,700 feet of rusty weathering gneiss. Below this again is 3,000 feet of limestone with bands of amphibolite underlain by 2,000 feet of amphibolite. Limestone, again, forms the base of the exposure,[2] so that it is probable that the gneiss and limestone, and amphibolite and limestone, are only a local variation of the quartzite and limestone of the other parts of the Continent. The difference may possibly be accounted for by a less average depth of ocean during the deposition of each cycle.

Far North and across the Hudson Straits, and in the south of Baffin's Land, numerous bands of limestone again appear interbedded with micaceous, pyritous hornblende, and graphite gneiss. This series is probably from 20,000 to 30,000 feet in thickness, and of the same age, in part at least, as the Grenville series.[3] Similar sandstones, aluminous shale, and limestone were spread all over the region of New York, and now form the Adirondack Mountains. The sandstone is now altered to mica schist, the shale to hornblende schist, and the limestone to marble.[4] Dr. Sterry Hunt has described

[1] A. Winchell, "A Last Word with the Huronian." *Bull. Geol. Soc. Am.*, vol. ii., 1891, p. 99.

[2] F. D. Adams and A. E. Barlow, "The Geol. of the Haliburton and Bancroft Areas, Province of Ontario." *Geol. Survey Canada, Mem.*, vol. vi., 1910, p. 31.

[3] R. Bell, "The North Side of Hudson Strait." *Geol. Sur. Canada, Ann. Rep.*, n.s., vol. xi., 1898, pp. 25, 28 m.

[4] J. F. Kemp, "Crystalline Limestone and Schists of the Eastern Adirondacks." *Bull, Geol, Soc, Am.*, vol. vi., 1895, p. 261.

another sequence of these rocks in Ontario, where six alternations of red gneiss, hornblende schist, and limestone reach a total depth of 34,000 feet.[1] The Shushwap series of the Rocky Mountain region of Columbia resembles the Grenville,[2] so that with only slight variation, the pre-Cambrian rocks probably originally covered practically the whole of the North American Continent.

Chemical Analyses of Pre-Cambrian Rocks.—Gneiss, schists, and limestone of several grades in Manhattan Island, whose age is somewhat uncertain, and may be more recent, have been chemically analysed with the following results, to which is added the composition of an acid sample from Ontario. These results, and the table which follows it, fully bear out and confirm the details already given. The gradational sedimentary differentiation from the highly siliceous quartzites and gneiss to the highly calcareous limestone and dolomite is repeated again and again in all ages, and in widely separated parts of the world, to the base of the stratified record :—

	SiO_2, Silica.	Al_2O_3, Alumina. FeO, Fe_2O_3, Oxide of Iron. MnO, Manganese Oxide.	CaO, Lime. MgO, Magnesia. CO_2, Carbon Dioxide.	Total.
	Per cent.	Per cent.	Per cent.	Per cent.
Dolomite limestone,	1·3	0·77	97	99·0
Hornblende schist, .	42·97	36·09	17·1	96·1
Mica gneiss,[3] . .	63·98	23·93	4·76	92·6
Mica gneiss, Ontario,[4]	79·7	9·2	1·43	90·3

Analysis of mashed and foliated pre-Cambrian schists of Nevada.[5]

SiO_2, Silica.	CaO, Lime. Co_2, Carbon Dioxide.	Total.
Per cent.	Per cent.	Per cent.
22·4	57·6	80·0
30·3	50·8	81·1
62·6	8·2	70·8
71·5	2·5	74·0
73·4	1·6	75·0

[1] Dr. T. Sterry Hunt, "Azoic Rocks of Pa." *Second Survey Pa. E.*, 1875, p. 174.

[2] G. M. Dawson, "Geol. Record of the Rocky Mountain Region in Canada." *Bull. Geol. Soc. Am.*, vol. xii., 1901, p. 63.

[3] A. A. Julien, "Genesis of the Amphibolite Schists and Serpentines of Manhattan Island, New York." *Ibid.*, vol. xiv., 1903, pp. 426, 439, 450.

[4] F. D. Adams and A. E. Barlow, "The Geol. of the Haliburton and Bancroft Areas, Ontario." *Geol. Survey Canada, Mono.*, vol. vi., 1910, p. 187.

[5] H. W. Turner, "Geol. of the Silver Peak Quadrangle, Nevada." *Bull. Geol. Soc. Am.*, vol. xx., 1909, p. 232.

The schists represented by these analyses may include a proportion of impregnated igneous material, but if this is the case, the actual analysis only would be affected, the relative composition would be little altered. The percentage of the oxides of iron and aluminium are not recorded.

Laurentian Sedimentary Cycle.—At a lower geological horizon than the Huronian system of America, and the Cuddapah rocks of India, and separated from them by a great break or discordance, are the Upper Laurentian or Keewatin, and Dharwar or Bijwar rocks in these respective countries. They are isolated remnants of an originally widely extended formation,[1] which has been denuded from above and absorbed from beneath. They are principally composed of igneous rocks with a subordinate amount of distinctly sedimentary material in the form of iron-bearing beds, hornblende, and chlorite schists, altered clay slate, and slaty rocks, with interstratified ferruginous and siliceous dolomite,[2] that is in the Lake Superior region; in Central Canada they consist of conglomerate, quartzite, gneiss schist, and limestone, having the usual relationship to one another.[3] The Dharwar is the oldest of the transition rocks of India, and closely resembles the Keewatin in every way. It also consists of conglomerates, quartzites, hornblende, and clayey schists, hæmatite schists and crystalline limestone.[4] Where the limestone is missing, on account of denudation, the more pelagic sediments remain in the form of pure white quartzites, mica, hornblende, and chlorite schists with calcareous and ferruginous bands.[5]

The ancient igneous complex forming the base of the geological column almost invariably contains a subordinate amount of rocks with sedimentary affinities. They form bands, streaks, and lenticels interlaminated with the plutonic igneous ground mass, and have been squeezed and partially melted by the plastic granite in which they were involved, and may often be remnants of the rocks just described. The Bengal gneiss contains many such remnants in the form of parallel bands of quartzite, quartz-pyroxene, crystalline calcareous rocks, and limestone, all sharply folded and intersected in every direction by granite dykes.[6]

[1] R. Bruce Foote, "Geol. Notes on Traverses through Mysore." *Geol. Survey Mysore, Mem.*, vol. i., 1900, p. 5.

[2] C. R. van Hise and C. K. Leith, "The Geol. of the Lake Superior Region." *U.S. Geol. Survey, Mono.*, vol. lii., 1911, p. 145. W. H. Smith, "The Archæan Rocks West of Lake Superior." *Bull. Geol. Soc. Am.*, vol. iv., 1893, p. 342, etc.

[3] A. C. Lawson, "The Internal Relation, etc., of the Archean of Central Canada." *Ibid.*, vol. i., 1890, p. 183.

[4] R. Bruce Foote, "Geol. Notes on Traverses through Mysore." *Geol. Survey Mysore, Mem.*, vol. i., 1900, p. 4.

[5] J. M. Maclaren, "Notes on Auriferous Tracts in Southern India." *Geol. Survey India, Records*, vol. xxxiv., 1906, pp. 100-104.

[6] R. D. Oldham, *Manual of Geology of India*, 1893, p. 30. L. Leigh Fermor, "The Petrology and Manganese Ore Deposits of the Sausar Tahsil, Chindwara District." *Geol. Survey India, Record*, vol. xxxiii., 1906, p. 166.

The Fundamental Complex of Scotland also contains similar inclusions, which have the same relation to the igneous rocks with which they are associated, and range from sedimentary gneiss, of various composition, to pure limestone represented by the following analyses :—[1]

SiO_2, Silica.	Al_2O_3, Alumina. FeO, Fe_2O_3, Oxides of Iron. MnO, Manganese Oxide.	CaO, Lime. MgO, Magnesia.	Total.
Per cent.	Per cent.	Per cent.	Per cent.
1·4	1·86	96·36	99·6
9·7	3·38	86·65	99·7
not recorded	1·3	48·9	..
46·1	40·17	6·5	92·7
75·3	16·1	2·8	94·2

The Keewatin and Dharwar sediments and these inclusions, although so ancient, yet preserve evidence of the original sedimentary differentiation. Below them we take leave of the unmelted sediments, and have to deal with the origin of rocks which have been liquefied, and consequently have lost all evidence of original stratification. They will be considered separately in a subsequent chapter.

Alternative Cycle Discussed.—The generally accepted theory of the formation of the basal sandstones and quartzites of each cycle attributes them to an increasing depth of water, and assumes that the limestone was laid down after the oceans had reached a maximum depth. In the first place, this requires that at no period of the earth's history have the oceans been more than from one-third to one-tenth of the depth they are at present, which is obviously most improbable. In the second, it is based on the similarity between some ancient sandstones and the very complex terrigenous muds and sands, of very limited range, which fringe present shore lines down to 600 fathoms, and derived principally from the land. That is to say, as a basis of comparison, we have a cycle consisting of limestone, followed by greensand and fragmental sandstone from below upwards. The silica decreases in the globigerina oozes to almost *nil*, forms a high percentage in, but varies considerably throughout the terrigenous deposits. The carbonate of lime suddenly changes from 98 per cent. in the calcareous deposits to about 47 per cent. in the greensands, and is also very variable in proportion in the sands as the shore line is approached.

The older sedimentary cycles of quartzite, shale, and limestone do not agree with this either in arrangement or chemical composition. The quartzite is always at the base, and the chemical

[1] B. N. Peach and Associates, " The Geol. Structure of the North-West Highlands of Scotland." *Mem. Geol. Survey U.K.*, 1907, pp. 76, 82, 231.

gradation is constant in all ages, as has been shown. Instances have been selected, as far as possible, where the cycle commences with pure white quartzite analogous to the pure siliceous oozes below the 4,000-fathom line and overlain by shales and limestones analogous to the red clays and calcareous oozes, in order to compare like with like. It would perhaps be possible to select instances from the stratified rocks of two-fold cycles commencing with limestone and overlain by complex sands, but they would not cover the whole of the geological record as do the three-fold ones here adopted.

The view as to the depth of the ocean during the deposition of every such cycle is that it commenced with transgression and consequent deepening of the ocean, as generally accepted, and that it gradually became shallower throughout the long geologic era, during which each series of oozes was accumulated, one above the other, in the same order as in modern seas. It may also be shown that pure quartzites were frequently the first rocks to be laid down after each of the many transgressions recorded in the geological scale.

CHAPTER V.

THE METAMORPHIC ROCKS.

Passage from Sedimentary to Metamorphic Rocks—Recent Metamorphic Rocks and Ancient Unaltered Sedimentary Clays—Local Metamorphism —Principal Agents which effect these Changes—Dynamic Metamorphism —Thermal Metamorphism—Aqueo-thermal Metamorphism—Metamorphism in Final Stages—Relations of Vesicular and Crystalline Texture of Granite — Relation of Metamorphic Rocks to Granite — Igneous Rocks a System or Group of Systems—Metamorphism and Origin of Igneous Rocks—Plutonic Rocks and Inclusions—Complexes of Various Ages Described and Compared—Tertiary Complex—Secondary Complex—Primary Complex—Fundamental Complex—Origin of Basement Complex by Analogy.

THE sediments of all the older systems referred to in the last chapter have greatly changed since they were laid down. The natural order and constant relationship of all the series of visible deposits of the earth's crust indicate the comparative age of each, as well as the origin. The present chapter is devoted to a consideration of the principal factors which have produced the crystalline and schistose condition which is not explained by age.

Passage from Sedimentary to Metamorphic Rocks.—The present state of the sediments of each system, from the oozes of the recent to the crystalline rocks of the deep-seated and oldest, graphically represents the various stages of rock evolution. In the upper divisions they pass from the calcareous ooze through the friable white earth of the Tertiary age to the compact chalk of the secondary, the stone of the Primary, and finally the crystalline marble of the pre-Cambrian. A similar gradation is observable in the lowest or siliceous rocks. The oozes pass into clays and sands, these into marls and sandstone, and they become slates and quartzites. These changes are termed metamorphism, and although chalk and marls are metamorphosed oozes, the term is usually confined to the greater changes which have produced the coarsely crystalline condition of the rocks deep down in the interior of the earth.

Recent Metamorphic Rocks and Ancient Unaltered Sedimentary Clays.—Antiquity accounts for some stages in rock development, but time alone will not produce all the alteration which many rocks

have endured. Some of the younger sedimentary rocks have become highly crystalline, and are an almost exact parallel of older schists. While, on the one hand, there are many rocks of comparatively recent formation which resemble the very ancient; on the other, very old ones have not suffered the same degree of change, and are difficult to distinguish from recent ones. As an instance of the former, shales of Secondary age in the Alps have been reduced almost to crystalline schists, and Tertiary deposits have become slates which are commercially useful,[1] and limestone, marls, and sandstone have been converted into marble, mica-schist, and gneiss.[2] As an instance of the latter, early Primary deposits in Russia still remain almost in their original form of blue plastic clays.[3] Silurian strata are represented by shales and sandstones as incoherent as those of Tertiary age round London and by clays so plastic, that they may be used for modelling, so entirely have they been exempted from the influence of the metamorphic action.[4]

Local Metamorphism.—The results of the metamorphic process may be detected within relatively limited regions, as well as in passing from system to system. The same strata may be followed for a long distance. "At one end stand rocks which are unmistakably of sedimentary origin, for their original clastic structure and bedding can often be distinctly seen, and they also sometimes contain organic remains similar to those found in ordinary unaltered sedimentary strata. At the other end come coarsely crystalline masses, which in many respects resemble granite, and the original character of which is not obvious. An apparently unbroken gradation can be traced between the two extremes."[5] Many undoubted sedimentary deposits have been transformed into crystalline rocks which it is difficult to distinguish from granite. "Thus the remarkable fact is brought home to the mind that ordinary sandstones and shales may in the course of ages be converted by underground changes into crystalline granite."[6]

Principal Agents which effect these Changes.—The recognised metamorphic agencies may be considered under three separate heads: Dynamic, Thermal, and Aqueo-thermal, and it is convenient to discuss them in this way.

Dynamic Metamorphism.—It is believed that these changes have been produced from time to time through the intense folding of the stratified rocks which has been effected during periods of mountain building. The contortion often bears evidence of the excessive

[1] Sir A. Geikie, *Text-book of Geology*, 4th ed., 1903, p. 804.

[2] Sir C. Lyell, *Elements of Geology*, 6th ed., 1865, p. 306.

[3] E. F. H. Kayser, *Text-book of Comp. Geology*, trans. by P. Lake, 1893, p. 26.

[4] Sir J. Prestwich, *Geology: Chemical, Physical, and Stratigraphical*, vol. i., 1886-8, p. 66.

[5] Sir A. Geikie, *Text-book of Geology*, 4th ed., 1903, p. 244.

[6] Sir A. Geikie, *Geological Sketches*, 1882, p. 327.

strains which the rocks have endured, and it is observed that where the distortion is greatest metamorphism is most complete. Some geologists think that these results are produced deep down in the earth's crust before upheaval takes place, so that they are initiated by the enormous pressures due to gravity, beneath the mass of overlying strata.

The B timore gneiss illustrates this very clearly. An ancient sedimentary series has been completely recrystallised and indurated under the influence of tangential thrust, combined with gravity and the injection of igneous material. Argillaceous sediments have been converted into gneiss and schist, the arenaceous sediments into quartzite and quartz schist, and the calcareous material into marble, the region having been thrown into a series of long folds.[1]

The Wu-t'ai sedimentary strata of China are now complexly folded, and schistose and most of the strata have had the original composition and structure obliterated by metamorphism. The changes of form are of an intense and universal character, and accompanied by an equally general change of constitution. All the mineral constituents have been recrystallised and have entered into new combinations, which has been accomplished under great pressure.[2]

Thermal Metamorphism.—Metamorphism may often be traced to the action of heat. Where Plutonic rocks have been intruded among the schists and sedimentaries, the strata are altered at the contact with the molten mass. The degree of change varies with the distance from the intrusive rock in such a way that the effect is clearly accounted for by the previous heated or molten condition of the granite.

For instance, the granite highlands of Ontario are fringed by ancient sedimentary rocks, and there is a progressive increase of metamorphism as the centres of former igneous activity are approached. In nearly every geological system, these igneous bosses, dykes, and sills have been forced among the sediments or poured out upon them. The strata beneath or around the flows have suffered metamorphic changes to a greater or less degree.

Near the intrusive bosses of Skiddaw, where they come into contact with slate rocks, grey grits have been metamorphosed at a moderate temperature, and become crystalline quartz, felspar, and mica. At the actual point of contact, which can only be seen under the microscope, the rocks of so widely different type are almost identical in character.[3]

Ancient schistose sediments are converted into crystalline gneiss

[1] F. Bascom, "The Piedmont District of Pennsylvania." *Bull. Geol. Soc. Am.*, vol. xvi., 1905, p. 293.

[2] Bailey Willis and Eliot Blackwelder, *Research in China*, vol. i., part 1, 1907, pp. 116, 164.

[3] R. H. Rastall, "The Skiddaw Granite and its Metamorphism." *Quart. Journ. Geol. Soc.*, 1910, p. 136.

by igneous impregnation. An infinite number of fine intrusive veins permeate the rocks. In extreme cases the invading granite forms a large proportion of the whole, and has not only penetrated between the folia, but between the individual mica plates, and produced a high degree of crystallisation.[1]

Where basaltic dykes have cut their way through the cretaceous rocks, while in the state of igneous fusion, the chalk has been changed to marble where it comes in contact with the intrusive mass.[2] Since it is always possible to distinguish between marble and basalt, the metamorphism is clearly due to the high temperature of the dyke at the time of its eruption.

Aqueo-thermal Metamorphism.—" In all forms of metamorphism water is the chief agent." [3] The liquid which remained in the sediments at the time of their formation has been effective in promoting and assisting the processes. It was imprisoned in the sediment, so that when this was overlain by great depths of strata, such as surmount the rocks deep in the interior of the earth, the pressure and temperature were raised to a high degree of intensity. The temperature of the enclosed water was raised in a corresponding measure, but the pressure prevented it from changing to steam, so that the highly heated moisture spread through the rocks with all its chemical energy ; " a destroyer of cohesion, a powerful solvent, and a promoter of decomposition preparatory to recomposition." [4] Rocks, which under normal conditions are brittle and glassy, become plastic under the influence of highly heated moisture, and accommodate themselves by contortion and folding to the inequalities of pressure upon them. In this way dynamic and aqueo-thermal action unite to produce a greater degree of change.

Metamorphism in its Final Stages.—The demonstration that igneous rocks are capable of producing many of these changes suggests that they are a distinct and separate constituent of the earth's crust, and have no generic relation to the sedimentary rocks. Some geologists have gone so far as to say that they are of entirely separate origin, but this is not necessarily the case. They are closely related to the sedimentary rocks in chemical composition, as will be seen, and resemble some altered sediments in lithological structure. Igneous rocks contain a small quantity of water, which has remained within them since the time of their formation. This, and other facts, suggest that they may be fused sediments, and the extreme phase of alteration under pressure.

Relations of Vesicular and Crystalline Texture of Granite.—" In rocks of large intrusive masses one may see with a powerful microscope

[1] T. O. Bosworth, " Metamorphism around the Ross of Mull Granite." *Ibid.*, 1910, p. 383.

[2] H. Credner, *Traité de Géologie*, 1879, p. 288.

[3] J. N. Le Conte, *Elements of Geology*, 1903, p. 232.

[4] J. D. Dana, *Manual of Geology*, 4th ed., 1895, p. 323.

exceedingly minute cavities, to be counted by millions to the square inch, in which the gaseous water which the mass contained was held imprisoned under the immense pressure of the overlying rock."[1] In the quartz of some granite there are innumerable cavities, which make up as much as 5 per cent. of the volume. When a granite is heated to 1,000° it gives off 89 times its own volume of steam in vapours. It was present in the deep-seated interior under the original conditions of solidification.[2] Eruptive lava is usually impregnated with great quantities of steam, which is due to the water which was imprisoned within it at the time of formation, and not to subsequent infiltration.[3] As soon as a lava flow reaches the surface the steam in the superficial layers seeks to escape, and expands in volume, and even explodes. Innumerable spherical cavities are formed in the semi-liquid mass, and the cooled rock resembles honeycomb, and is spongy in appearance. The vesicular granite by liquefaction and emission becomes a porous lava. Between the two extremes, a gradation of vesicular texture is produced, according to the depth at which the igneous material cooled down.

The depth at which the molten rock solidified governed the rate of cooling, and at the same time the mass has also assumed a varying degree of crystalline texture. In the deepest parts, where the vesicles were finest, the crystals are coarsest, and *vice versâ*. Dykes and sheets which have cooled more slowly than lava and more rapidly than greater bosses form an intermediate grade. The same gradation is sometimes seen in the lava itself. In a large mass, where the surface is spongy, the interior is finely crystalline, resembling fine-grained granite, because the inner layers have cooled more slowly, and is sometimes so coarsely crystalline in structure as to be taken for granite by a casual observer. "We know that the same molten mass solidifies at great depths as a granite or wholly crystalline rock, and at the surface as a rhyolite or other semi-crystalline lava."[4]

Relation of Metamorphic Rocks to Granite.—Thus the relationship between the various types of eruptive rocks may be traced by means of the degree of crystalline texture and the vesicles which permeate them. There is an observable gradation from a once molten lava to a massive granite, and although we are unable to observe the change from an eruptive granite to a metamorphic granite, or altered aqueous sediment, the resemblance between them may be so close that it is highly probable that the eruptive stage has succeeded the metamorphic stage,[5] and that there are all grades between water containing mineral matter in solution and

[1] W. H. Norton, *Elements of Geology*, 1905, p. 273.

[2] R. T. Hill, "Pélé and the Evolution of the Windward Archipelago." *Bull. Geol. Soc. Am.*, vol. xvi., 1905, p. 285.

[3] H. Credner, *Traité de Géologie*, 1879, p. 261.

[4] J. Geikie, *Earth Sculpture, or the Origin of Land Forms*, 1898, p. 140.

[5] W. B. Scott, *Introduction to Geology*, 1897, p. 293.

a molten magma containing water in solution.[1] A sedimentary granitic gneiss[2] seems to be the link between the two classes of rock, for if its banded structure be obliterated by melting it becomes a true granite.

It is thus evident that the metamorphic processes may effect all the changes required to produce a lava or other eruptive rock from an oceanic ooze. In fact, the constant accumulation of sediment upon the ocean bed may be the cause, as we have seen, of the metamorphic processes within the sediments themselves, which ultimately change them to lavas when the depth is sufficiently great. Whether this has actually been accomplished in nature is, of course, beyond actual demonstration, but it is a quite reasonable deduction from many observed facts, as will be seen.

Igneous Rocks a System or Group of Systems.—Thus far it is certain, however, that the basal granites, which represent the first chapter of the earth's history, are allied to more recent volcanic lavas, and, "as far as their mode of formation is concerned, there is no difference between the ancient eruptive rocks and the volcanic products of the present time." [3] That is to say, that igneous rocks of all ages, whether primitive bosses, dykes, and sills of more recent age, or lava cones of to-day, are of similar origin, and for our purpose may be considered as one and the same class. We may treat them as a system, distinct from any other system, as the Primary is a distinct system or group of systems in itself, and as such will form the subject of a separate chapter.

Metamorphism and Origin of Igneous Rocks.—The metamorphic processes may thus be divided into two classes. Those which are continually in progress in the deep interior, where the rocks are subjected to enormous pressures, may be distinguished from others which are due to the contact of liquid rock with adjacent sediments or previously metamorphosed rocks. The former are deep-seated and slow in action, while the latter may operate nearer the surface, and have comparatively rapid effects. This class of phenomena, not only thermally alters the strata it approaches, but often effects great dynamic changes in them, such as fracture, contortion, and thrusting. It is, therefore, obvious that the final result of the first class or liquefaction far beneath the surface is but the prelude to a commencement of similar operations by the mass of fused rock itself, so that although in one sense they may be distinguished, in another they are related, and one leads up to the other.

The available information relating to the metamorphism by the protrusion of granite in a liquid or plastic state has an important

[1] J. N. Le Conte, *Elements of Geology*, 5th ed., 1903, p. 232.

[2] R. D. Oldham, "Geol. of N.W. Himalayas." *Geol. Survey India, Record*, vol. xxi., 1888, p. 150.

[3] H. Credner, *Traité de Géologie*, 1879, p. 272.

bearing upon the origin of the material of which magmatic granite is composed.

Plutonic Rocks and Inclusions.—It appears that protracted epochs of sedimentation have always been succeeded by intervals of vulcanism. The geological records point to the recurrence of volcanic outbursts after each important system has been laid down. It is consequently probable that the accentuation of pressure has produced internal stresses under gravity, and that momentary relief of pressure or rock creep has caused fusion to commence in the interior, and the products have found their way to the surface.[1] Once the lower layers have become liquid or re-fused, the molten mass absorbs the adjacent rocks and wells upwards.

It was originally thought that the magma forced its way upwards towards the overlying sediments, and disturbed them in the process, but although this, no doubt, has often taken place, it is now more generally recognised that the thermal energy of the molten rock is sometimes greater than the dynamic and rocks are absorbed or replaced by it. The examination of the contact between the once molten magma and the invaded region reveals fragments and masses of rock of all sizes, forming inclusions in the granite matrix, which evidently cooled down before they were melted. The composition of the invading rock is also altered at the plane of transition; it is contaminated.

Complexes of Various Epochs Described and Compared.—There are numerous instances where igneous rocks of this character have been exposed by denudation long after they had cooled down, and now form the surface rock for thousands of square miles, or the granite core of a mountain chain. In such instances, the surface presents a highly interesting and complex structure. The fragments of partially melted rock form bands, streaks, and blotches set in a ground mass of granite, and compose a mosaic of different colours and shapes.

These features are characteristic of the sub-Tertiary gneisses of the Himalayas, of the sub-Cretaceous pavement of the Sierra Nevada and Central China, of the Primary complex in the Appalachian region, of the Laurentian shield of Canada and Peninsular India, and the Fundamental Complex of Scotland.

A description of these rocks in the various parts of the world mentioned shows that one account might be applied to all. The more recent type is the first to be mentioned, and it is followed by instances from older and older periods until the most ancient are reached.

Tertiary Complex.—Massive Plutonic intrusions in the shape of elongated ovals, 30 miles long and 4 miles wide, rise to heights approaching 10,000 feet in the Deserts of Baluchistan and Persia.

[1] J. P. Iddings, "The Origin of Igneous Rocks." *Bull. Washington Phil. Soc.*, 1892, p. 181. A. Harker, *Nat. History of Igneous Rocks*, 1909, p. 13.

They are isolated portions of the magma similar to those which form the core of all the more recently formed mountains of Central Europe, the Himalayas, and the Rocky Mountains of America. All round the margin of these masses, fragmentary inclusions of sedimentary strata of Eocene age may be seen. Both the invaded rock and the instrusive rocks have been altered where they come in contact. Shales have been thermally altered and metamorphosed, and the igneous mass is different in character near the boundary.[1] Dynamic changes and disturbance have also been brought about, while dykes thrown off from the main intrusion penetrate the stratified rocks. The accompanying diagrams illustrate the results of rock melting. Fig. 6 shows inclusions of sedimentary rock in the body of the

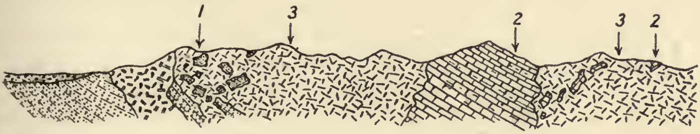


Fig. 6.—Section of Tertiary Batholith, 2¾ miles across, showing absorbed Cambrian Quartzite (1) and Carboniferous Limestone (2) by Igneous Rock (3) in the Rocky Mountain Region of Utah. (S. F. Emmons, *U.S. Geol. Survey, Atlas folio* 65.)

igneous mass which cooled down before they were fused. The parallel section shows the same strata wholly unaffected by the magmatic fusion. If the granite mass had been intruded into these sediments they would have been thrown into a high state of confusion and further contortion.

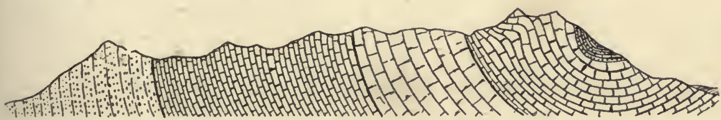


Fig. 7.—Parallel Section, 1 mile from the above, showing same Rocks unaffected by the Intrusion.

Secondary Igneous Complex.—At a somewhat earlier period, during the late Cretaceous, the Coast Ranges of America,[2] and a great

[1] E. Vredenberg, "A Geol. Sketch of the Baluchistan Desert and part of Eastern Persia." *Geol. Survey India, Mem.*, vol. xxxi., 1901, p. 230. R. D. Oldham, "Geol. of North-West Himalayas." *Geol. Survey India, Record*, vol. xxi., part 4, 1888, pp. 154-5. F. H. Smith, "Geol. of Tóchi Valley." *Ibid.*, vol. xxviii., 1895, p. 110. R. A. Daly, "The Okanagan Composite Batholith of the Cascade Mountain System." *Bull. Geol. Soc. Am.*, vol. xvii., 1906, p. 361.

[2] J. S. Diller, "Cretaceous and Early Tertiary of Northern California and Oregon." *Ibid.*, vol. iv., 1893, p. 223.

east and west chain stretching through China and Tibet,[1] were elevated above the sea level by similar causes. This revolution was also effected by the upwelling of a granite magma, which elevated the pre-Cretaceous rocks.[2] The basement complex may here be composed of fused Primary or Secondary strata, and consists of granite and crystalline schists, by far the greater portion of which is gneissoid. Quartz, hornblende schist, and limestone appear in lenticular form, both in the gneiss and granite, or again, chunks and layers of calcareous rock may be imbedded in the granite.[3] The schists and quartzites form the roof of high Batholiths, and project deep down into the heart of similar granitic protrusions of the same age in British Columbia. Great depths of sedimentary crust have been attacked from beneath and displaced or replaced by the molten magma.[4]

Primary Complex.—The Western States of North America are underlain by a very similar granite complex of Mid or late Primary age, and consequently vastly older than the Eastern basement. Massive and foliated granite contains schist inclusions which have been absorbed by the igneous intrusions. Portions of the mass may be the original slate, highly impregnated by the gneiss paste, but so highly changed that they more closely resemble granite than the original strata. It is a fine study of the metamorphism of sediments, foliation of eruptives, and obliteration of stratification.[5] In Pennsylvania it consists of a badly crumpled mass of strata, all more or less thoroughly crystalline, every grade of thick and thin beds, every colour of grey to nearly white and black, and nearly every possible mixture of minerals, syenite-granite, iron ores, and hornblende passing into one another and overlying one another yet belonging to one age.[6] Gneiss of this description is widely distributed in New York, New England, Maryland, Virginia, Pennsylvania, and Columbia.

Fundamental Complex.—Descending still further in the geological scale, we encounter the rocks which underlie the pre-Cambrian systems. This is a very much older complex still, and has been termed the Fundamental gneiss. It is exposed for thousands of square miles over Canada and Peninsular India as the surface rock, and crops out in many more isolated spots, as in the Lewisian

[1] Bailey Willis, *Research in China*, vol. ii., p. 14. Sir T. H. Holland, "General Report, 1903-4." *Geol. Survey of India, Record*, vol. xxxii., 1905, p. 155.

[2] H. W. Fairbanks, "Review of our Knowledge of the Geol. of the Californian Coast Ranges." *Bull. Geol. Soc. Am.*, vol. vi., 1894, pp. 81, 91.

[3] G. D. Louderback, "Basin Range Structure of the Humboldt Region." *Ibid.*, vol. xv., 1904, pp. 318, 327.

[4] R. A. Daly, "The Okanagan Composite Batholith of the Cascade Mountain System." *Ibid.*, vol. xvii., 1906, p. 336.

[5] C. H. Hitchcock, "New Studies in the Ammonoosuc District of New Hampshire." *Bull. Geol. Soc. Am.*, vol. xv., 1904, pp. 466-480.

[6] J. P. Lesley, *Summ. Descrip. Geol. Pa.*, vol. i., 1892, p. 68.

Highlands of Scotland. The description of this ancient complex is a repetition of those already described, but the question of the origin is so important that it is necessary to discuss it in some detail.

Bosses of red granite are seen to have fused the ancient floor beneath the Huronian rocks of Lake Huron. They protrude through the basal quartzites, and masses of this rock, a quarter of a mile in length were caught up in the gneiss. The disturbance of the sedimentary beds caused the quartzites to dip into and under the plastic rock, and it now appears as white patches in the red gneiss ground.[1]

The rolling glaciated Laurentian highlands of the Canadian Northern Shield are largely composed of vast bubble-like mounds, which welled upwards during the earlier periods of the earth's history. They are not all of the same age, and it is a task beset with great difficulty to determine the time at which a given protrusion last cooled down. There is evidence to show that some parts were in a plastic state at a far subsequent period to the final cooling of other portions, so that fusion and cooling have taken place repeatedly. The actual period or frequency of this does not affect the present argument, since in the instance to be quoted this took place at an exceedingly remote period.

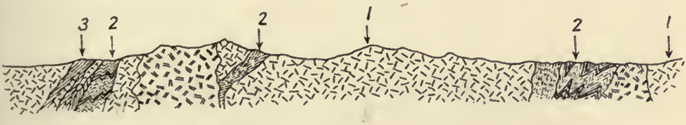


Fig. 8.—Pre-Cambrian Basement Complex (1) of Arizona, with Inclusions of Sedimentary Schists (2) and Metamorphic Rocks (3); 10 miles across. (F. A. Jaggar and C. Palache, *U.S. Geol. Survey, Atlas folio* 126.)

These batholiths, as they are termed, rose, displayed, frayed out, metamorphosed, and absorbed the lower sediments. The old basement upon which the latter were deposited was re-fused, and the clastic material sank down into the molten or plastic magma.[2] The fragmentary inclusions, which are of all sizes and shapes, were rigid masses at the time when the granite flowed round them. Large solid portions of black amphibolite fell into the granite magma, and were resolved into a swarm of fragments, and some of these could be re-assembled into the original form.[3] In other instances limestone has been highly altered where the gneiss has invaded it, and, as a result, the altered limestone and true igneous rock are often indistinguishable from one another, and have a similar chemical

[1] A. E. Barlow, "The Laurentian and Huronian of Lake Huron." *Bull. Geol. Soc. Am.*, vol. iv., p. 318.

[2] A. E. Barlow, "Geol. of Nipissing and Timiskaming Map Sheets." *Geol. Survey, Canada, N.S.*, 1908, part 2, p. 98.

[3] F. D. Adams and A. E. Barlow, "Geol. of the Haliburton and Bancroft Areas, Ontario." *Geol. Survey Canada*, 1910, *Mem.* 6. pp. 74, 75, 121.

composition. Long after the magma cooled down, the stratified rocks above it were removed by erosion, and the surface of the bosses erased and smoothed, so that the inclusions now appear as bands, streaks, and lenticels, stretching for miles across the surface of the hills.

The Fundamental Complex of China mainly consists of massive intrusions of red and grey granite and dark biotite schists ramified by later igneous dykes, together with the usual proportion of quartzose gneiss, sericite-, amphibolite-, and biotite- or other schist and marble of all sizes, all of which are of sedimentary origin.[1] Such is also the Fundamental Gneiss of Scotland, being chiefly composed of light-tinted granite of average acidity with dark segregations, in the form of blotches and bands, which are crossed and recrossed by more acid veins (see Plate II., Fig. 1). There is also a minor proportion of rocks of all grades with sedimentary affinities which were involved in the igneous rock, while in a plastic state, and have consequently suffered deformation of various kinds.

Below the Keewatin system of the Lake Superior region the rocks are probably of even greater antiquity than those already described. The solid floor upon which these upper Laurentian sediments were deposited has not so far been traced, so that the

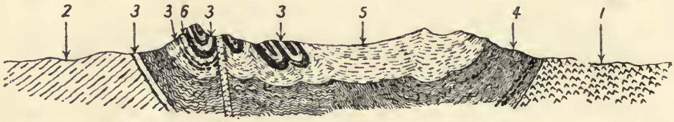


Fig. 9.—Band of Quartzites, Schists, and Limestone, 4½ miles wide, infolded in the Granite and Gneiss Complex of Madras.—1, Granite. 2, Gneiss. 3, Quartzite. 4, Hornblende Schists. 5, Chlorite Schists. 6, Limestone. (P. S. Vyengar, *Records Mysore Geol. Dep.*, vol. vi.)

lowest limit is an eruptive contact. The oldest beds have been dissolved by the molten rock beneath and strips, blocks, and fragments are imbedded in it and partly digested.[2] The basal gneiss of the Indian Peninsula probably solidified at even an earlier epoch than the American, since the old floor beneath the Dharwar system, which is approximately the same age as the Keewatin, has not been fused. As in previous instances, it is separable into an older, dark red, pink, and white massive granitoid gneiss, often containing inclusions of foreign rocks,[3] and a younger of apparently stratified

[1] Bailey Willis and Eliot Blackwelder, *Research in China*, vol. i., part 1, 1907, p. 101

[2] W. G. Wilson, "Geol. of Nipigon Basin, Ontario." *Geol. Survey, Canada, Mem.*, vol. i., 1910, p. 52. A. C. Lawson, "The Internal Relations, etc., of the Archean of Central Canada." *Bull. Geol. Soc. Am.*, vol. i., 1890, p. 175.

[3] Sir T. H. Holland, "The Charnockite Series." *Geol. Survey India, Mem.*, vol. xxviii., part 2, 1900, p. 235.

beds of great variety, from quartzite to dolomite, which roll about, and dip at all angles,[1] and have been involved in the older granite.

These instances reveal the undoubted correspondence between the solidified molten magmas of exceedingly remote and comparatively recent geological periods. The Tertiary complex of Asia and the Gneisses of Canada, although widely separated from each other in distance and in time, are yet comparable with one another. Even within the Laurentian complex, sediments of Cambrian age have been involved, and it is difficult to distinguish the gneiss formed from them and the Fundamental Gneiss.[2]

Having noticed these resemblances, it remains to allow them to throw their light upon the origin of igneous rocks in general.

Origin of Basement Complex by Analogy.—It is persistently affirmed by geologists of undoubted repute that igneous rocks are younger than the sediments they invade. If this supposition were tenable, it would at once prove that the oldest rocks of the earth's crust are aqueous sediments, and would at the same time simplify the subject, but there are obvious difficulties in accepting this conclusion, although, in so far as their eruption and solidification are considered, they are younger than the associated strata.

If, indeed, lavas and traps are younger than the rocks they invade, it follows that in certain parts of the coast ranges of America and the Highlands of Tibet and China, there are no older rocks than the Cretaceous, while in some parts of the Rocky Mountains and Himalayas there are none older than the Tertiaries, and that sedimentation commenced at widely separated geological epochs in these neighbouring localities. This would not be impossible, if it could be shown that an old ridge or base of igneous rocks was above the sea during Cretaceous times, and formed the basement for the Tertiary sedimentation. But this would at the same time destroy the original argument, and demonstrate that the Tertiary complex is older than the Tertiary sediments, and not younger. The inclusion of Eocene strata in this complex proves that the old floor was fused in post-Tertiary times, whether that floor consisted of Secondary strata, as it does in other localities, or an older igneous complex. The rocks which were fused during post-Tertiary vulcanicity belonged to an older epoch, and were probably Secondary sediments. It is, therefore, highly probable that Tertiary igneous rocks consist of fused pre-Tertiary strata, and this is quite consistent with observation.

The Tertiary magma of the Cascade Ranges of British Columbia is believed to have worked its way upwards, replacing the invaded

[1] R. D. Oldham, *Manual of Geology of India*, 1893, p. 30.

[2] A. P. Low, "South Shore of Hudson Strait." *Geol. Survey Canada, N.S.*, vol. xi., 1898, p. 32 L.

rock.[1] Older systems represented elsewhere in Columbia are wanting in the Okanagan range. Great depths of sedimentary crust have been attacked from beneath and absorbed. The magma invaded the sediments quietly, and replaced cubic mile after cubic mile, until its energy failed.[2] The nature and present state of the granite core are explained by successive magmatic invasions, and the resulting rock is very similar in every instance. Again, almost at the base of the sedimentary column, beds of lower Huronian age have been dissolved by the molten rock beneath.[3] A suite of specimens from the Madras gneiss, under close examination, appears to be a series of rocks resulting from the various stages of mingling of igneous rock and sedimentary material, and the action of those upon the sedimentary mantle which overlaid the igneous mass.[4]

The argument deduced from these facts might, therefore, be applied to the plutonic rocks of every chapter of the earth's history already alluded to. They indicate the probability that the basement complex beneath each system consists of fused rocks of several preceding systems, and that the very oldest, or Archæan Basement Complex in particular, consists of melted pre-Keewatin sediments. The facts prove that they are so to a considerable extent; the analogy suggests that they are wholly so. The evidence from analogy will be further supported by the chapter upon the chemical analysis of igneous rocks.

"The metamorphic rocks prove to us that the earth has solidified from the centre outwards."[5] The igneous theory of the earth's origin is not borne out by the geological data. The globe was, therefore, never in a state of complete liquidity. And this is confirmed by other writers. "Nowhere amongst the lowest gneisses is there any structure observable which can be compared with the superficial portion of a lava cooled at the surface."[6]

[1] R. A. Daly, "The Okanagan Composite Batholith of the Cascade System." *Bull. Geol. Soc. Am.*, vol. xvii., 1906, p. 361.

[2] R. A. Daly, *Ibid.*, p. 368.

[3] A. P. Coleman, "Clastic Huronian Rocks of W. Ontario." *Ibid.*, vol. ix., 1898, p. 228.

[4] T. L. Walker and W. H. Collins, "Petrographical Study of some Rocks from the Hill Tracts, Madras." *Geol. Survey India, Record*, vol. xxxvi., 1907, p. 2.

[5] J. D. Dana, *Manual of Geol.*, 4th ed., 1895, p. 376.

[6] Sir A. Geikie, *Text-book of Geology*, 4th ed., 1903, p. 871

CHAPTER VI.

IGNEOUS DIFFERENTIATION.

Chemical Composition of Igneous Rocks—Various Causes of Igneous Differentiation—Process of Differentiation—Chemical Analysis of Differentiated Plutonic Cycle—Process of Cooling and Crystallisation—Average Composition of Sedimentary Systems—Igneous Magmas also of Average Composition—Alkalies in Igneous and Sedimentary Rocks—Mineral Salts in Rock Systems—Mineral and Chemical Composition of Granite—Igneous Rocks and Sedimentary Origin.

It is the chemical composition of the igneous and plutonic rocks that reveals their origin. They consist of the same minerals as the strata of the sedimentary systems, but differently arranged. The following table is compiled from actual results of the analysis of a large number of samples of igneous rock of all ages. At the acid end of the scale they actually agree with the sedimentary rocks, but during metamorphism and liquefaction the silica and silicates absorb or enter into molecular combination with the calcareous rocks, and form peridotites, serpentine, garnet, or olivine so that the calcareous elements do not reach so high a percentage at the ultra-basic end of the scale. The addition of carbon dioxide which is usually absent in igneous rocks would make the chemical compositions more nearly approach the sediments.

SiO_2, Silica.	Al_2O_3, Alumina. FeO, Fe_2O_3, Oxides of Iron.	CaO, Lime. MgO, Magnesia.	Total.
Per cent.	Per cent.	Per cent.	Per cent.
38·4	10·4	45·5	93·3
39·25	16·89	38·27	94·41
42·3	24·06	31·12	97·48
46·24	33·27	18·65	98·16
49·78	30·31	12·9	93·99
54·83	28·75	8·04	91·62
59·26	24·5	6·24	90·00
64·49	19·67	5·0	89·16
68·36	17·92	3·66	89·94
71·33	16·5	3·0	90·83
76·12	14·1	1·84	92·06
80·42	11·0	1·2	92·62
83·57	10·0	1·5[1]	94·07

[1] H. S. Washington, "Chemical Analysis of Igneous Rocks." *U.S. Geol. Survey, Prof. Papers,* vol. xiv., 1903.

Chemical Composition of Igneous Rocks.—The limestones of the pre-Cambrian rocks are usually magnesian, and are probably altered ordinary limestone, and the same change has affected the composition of the igneous rocks. The percentage of magnesia often exceeds the silica, but lime never does. In the foregoing table these two elements are added together, as in previous tables.

These figures are selected from a long list published by the United States Survey, without regard to the age in which they were erupted, but a similar variation of the three principal constituents is characteristic of every determined series of flows, although the range may not always be so wide.

The following table of analyses of some of the plutonic massifs of Peninsular India reveals their identity with the igneous rocks. The series represents some of the most ancient intrusive rocks we know of, and are probably all of about the same age :—

SiO_2, Silica.	Al_2O_3, Alumina. FeO, Fe_2O_3, Oxides of Iron.	CaO, Lime. MgO, Magnesia.	Total.
Per cent.	Per cent.	Per cent.	Per cent.
39·0	12·6	48·2	99·8[1]
46·8	26·1	27·6	100·5
53·3	34·7	9·4	97·4
63·7	23·8	8·8	96·5
72·9	17·2	2·9	93·0
75·5	18·8	1·6	95·9[2]

It will be noticed that in the foregoing tables of analyses the increase of silica is always accompanied by a decrease of carbonate of lime in the case of the sediments, and of lime in the case of igneous rocks, and that the ferro-aluminous constituents first increase and then decrease. The absence of carbon dioxide in igneous rocks is referred to later. Numberless samples, both of sedimentary and igneous rocks, might be quoted, where this principle is not maintained. This departure may, however, be accounted for, so that the ocean oozes being the basis of comparison, the uniformity appears to be the original.

Various Causes of Igneous Differentiation.—The igneous material represented by these tables has been ejected to the surface at repeated periods of the earth's history, and on account of certain affinities or behaviour of the simple oxides composing it, a separation has gone on within the liquid, by means of which a differentiation

[1] C. S. Middlemiss, "Notes on the Ultra-basic Rocks of the Chalk Hills near Salem, Madras." *Geol. Survey India, Record*, vol. xxix., part 2, 1896, p. 32.

[2] Sir T. H. Holland, "The Charnockite Series." *Geol. Survey India, Mem.*, vol. xxviii., part 2, 1900, p. 119, etc.

is again produced, and although this is not the same as in the sedimentary cycles, yet it bears a definite relation to it.

The actual cause of this differentiation has been the subject of much discussion and investigation. There are indications in the rocks of the Fundamental Complex that concentration has taken place round local centres during the plastic stage.[1] Many writers have thought that the minerals have arranged themselves according to their respective specific gravity, while the rock material was in a sufficiently liquid state for the more basic portion to fall and the more acid to rise. Molecular concentration of certain constituents in the cooler portions of the magma is another theory based upon the behaviour of salts in aqueous solution. Although these causes may contribute to the final result, the more probable explanation seems to be found in the crystallisation of the various minerals from the liquid mass as the temperature falls.

Process of Differentiation.—The notable igneous products of all ages have now been exhaustively examined and described, and it is shown that from the pre-Cambrian to the Tertiary times magmas have been generally of average composition. It is thus inferred that the chemical character of the magma was established before that time. The series of eruptions in each case has generally followed a similar order. The initial outburst is always or nearly always of the same average composition as the magma. Towards the close of every continuous series of eruptions, the flows are usually smaller in volume, and are widely different in composition from one another and from the initial flow. The usual succession is from a lava of average composition, through less siliceous and more siliceous flows to those extremely low in silica and others extremely high in silica. It may be stated generally that with slight variation each series commences with a mean and ends with extremes.[2]

Chemical Analysis of Differentiated Plutonic Cycle.—The following suite of analyses from a massive intrusion in America, in which the centre is more basic and the periphery more acid, shows the results of local magmatic differentiation very clearly. The various grades are integral parts of one mass of contemporaneous origin, and are not due to successive intrusions, so that the differentiation took place within the magma of which the intrusion formed a part.[3]

[1] B. N. Peach and Associates, "The Geol. Structure of the North-West Highlands of Scotland." *Mem. Geol. Sur. Gt. B.*, 1907, p. 72. Sir T. H. Holland, "The Charnockite Series." *Geol. Survey India, Mem.*, vol. xxviii., part 2, 1900, p. 219.

[2] J. P. Iddings, "The Origin of Igneous Rocks." *Bull. Washington Phil. Soc.*, 1892, p. 145.

[3] H. S. Washington, "Igneous Complex of Magnet Cove, Arkansas." *Bull. Geol. Soc. Am.*, vol. xi., 1900, p. 392.

SiO_2, Silica.	Al_2O_3, Alumina. FeO, Fe_2O_3, Oxides of Iron.	CaO, Lime. MgO, Magnesia.
Per cent.	Per cent.	Per cent.
36·5	19·8	27·0
38·9	24·7	22·0
41·7	26·8	19·28
49·7	26·5	10·23
50·9	27·4	4·7
53·3	23·7	3·6

Process of Cooling and Crystallisation.—The more generally accepted cause of this divergence or differentiation is difference, or change of temperature. The evidence available goes to show that the magma itself is never universally extended, either vertically or superficially, beneath the solid crust, but that it is confined to more or less local magma basins, so that the variation of temperature within the molten mass would produce initial differentiation before ejection. When, therefore, a large volume of lava is drawn off from the magma, the temperature of the remainder must fall, and a further tendency to differentiation be produced within it. The energy expended during every eruption, and contact with colder rocks near the surface would have similar effects upon the moving mass itself. In this way differentiation is in progress from the commencement to the conclusion of every eruption. The temperature of crystallisation is reached more rapidly in the initial effusion, and it remains more basic. The extreme differentiation is produced within the magma where temperature falls more slowly, so that the concluding flows are both acid and ultra-basic. In this way the great variety of rock composition is produced.

Average Composition of Sedimentary Systems.—The dynamic and thermal operations which have come to bear upon the rocks of the systems referred to in the last chapter have affected them in greater or less degree, according to age or circumstance. While this has been going on deep beneath the surface, other processes have been in operation upon the land and ocean bed, such as storm and calm, equatorial heat and Arctic cold, ocean currents, tides, waves, and rivers, all of which have been constantly changing the nature of the rocks exposed to their action, so that a different kind of rock is produced from them by mechanical operations. The effects of superficial and subterranean agencies contribute an important argument regarding the origin of the primitive rocks.

The compression, folding, and contortion of a series of sedimentary strata laid down in cyclic order produces a highly complex structure, and the minerals become intimately mingled. They indeed, become effectively mashed, so that the original state is lost in the great confusion. The erosion of a similar indurated group

which has been upheaved, and exposed to denudation by the exterior forces produces a conglomerate or other clastic rock consisting of fragments of all sizes and types. In this way the sandstones and conglomerates become equally heterogeneous by an entirely different process. Whether one system or several suffer these experiences, the result in each case is a heterogeneous mass.

The average mineral content of such a mass bears definite relation to the original sedimentary cycles. It is obvious that the average chemical or mineral composition of a complete and undisturbed cycle, consisting of highly siliceous sediments at one end of the scale and highly calcareous at the other, is intermediate or basic, according to the relative superficial extent of the highest and lowest layers. Under the conditions just referred to, it is equally obvious that the commingling in one case and erosion in the other produces a rock of average composition in the bulk.

Igneous Magmas also of Average Composition.—This agreement of average composition in highly and little disturbed systems is a further guide to the origin of the oldest rocks. The most striking features of the Fundamental Complex in Scotland and India are due to the mode of association of the lighter and darker varieties [1]—that is, of the rocks rich in felspar and quartz and those largely composed of ferro-magnesian minerals. A heterogenous mass has been formed in which spherical and globular lumps, lenticular bands, streaks, and laminæ exist in great variety. Every gradation from circular patches to streaks appear upon exposed surfaces, in such a way that they were undoubtedly produced by plastic deformation [2] (see Plate II., Fig. 1). It is impossible to say whether this was accomplished by the incomplete mingling of the lighter and darker varieties or by the partial separation of the darker by the lighter. Whichever interpretation is correct, it would make no difference to the present argument, since the general impression left after the examination of rocks from the whole area under review is, that if the mass were uniform, it would be of average or intermediate composition,[3] and, as we have seen, the liquid magma, whence all igneous products have been derived, is considered by the leading petrologists to be of average composition. That is to say, that not only are the igneous rocks composed of the same chemical compounds as the sediments, but are differentiated in a manner clearly related to the sedimentary differentiation, and are of approximately the same average composition. The relations are such that magmas may be derived from the fusion of stratified rocks.

[1] F. H. Hatch, "The Kolar Gold Field." *Geol. Survey India, Mem.*, vol. xxxiii., part 1, 1901, p. 4.

[2] B. N. Peach and Associates, "The Geol. Structure of the North-West Highlands of Scotland." *Mem. Geol. Survey Gt. Bt.*, 1907, p. 72.

[3] *Ibid.*, p. 56. Sir T. H. Holland, "The Charnockite Series." *Geol. Survey India, Mem.*, vol. xxviii., p. 214.

Alkalies in Igneous and Sedimentary Rocks.—The foregoing tables of rock analysis only include the four principal chemical constituents of the sedimentary and igneous rocks, and account for from 85 to 99 per cent. of the total composition. The alkalies—potash and soda—water, and other minor chemicals, have been omitted, but as the presence of alkalies in the igneous rocks requires explanation, if the present theory of rock generation is a valid one, it will now be considered.

It has been computed from the large number of analyses of volcanic and plutonic rocks now available, that on an average they contain about 3 per cent. of each of these,[1] so that if igneous rocks are derived from sediments by fusion under pressure, sufficient potash and soda should be found in the stratified rocks, in order that, if melted, they would produce a granite containing this small proportion. The possible sources of these chemical compounds, therefore, require to be stated, and the following table indicates their proportion in the composition of the various sediments of different ages :—

Sediment.	Potash, K_2O.	Soda, Na_2O.
Red Clay, modern,[2]	1·66	1·74
Blue Muds, modern,[3]	1·35	2·68
Ocean clays, average,[4]	8·0	6·0
Greensand, Secondary,[5]	2·3	1·03
Glauconite,[6]	4·2	·2
Shales, Silurian,[7]	3·7	·8
Slate and shale,[8] up to	7·8	7·0
Shales, average,[9]	3·2	1·3
Quartzite, Cambrian,[10]	12·6	·38
Mica Schists,[11]	·83-4·6	·36-4·02
Baltimore gneiss,[12]	2·69	3·2

[1] F. W. Clarke, "Analyses of Rocks and Minerals." *U.S. Geol. Survey, Bull.*, No. 419, p. 9.

[2] Sir J. Murray and Renard, *Challenger Reports: Deep Sea Deposits*, 1891, p. 201.

[3] *Ibid.*, p. 449.

[4] F. W. Clarke, "Analyses of Rocks and Minerals from U.S. Survey Laboratory." *Geol. Survey U.S. Bull.*, No. 419, 1910, p. 9.

[5] Sir J. Murray and Renard, *l.c.*, p. 449.

[6] A. J. Jukes Browne, "Cretaceous Rocks." *Mem. Geol. Survey Gt. B.*, vol. ii., p. 327.

[7] B. N. Peach and J. Horne, "Silurian Rocks." *Mem. Geol. Survey U.K.*, vol. i., 1899, p. 644.

[8, 9] F. W. Clarke, "Analyses of Rocks and Minerals from the U.S. Survey Laboratory." *U.S. Geol. Survey, Bull.*, No. 419, pp. 10, 214, 217.

[10] F. Bascom, "The Piedmont District, Pa." *Bull. Geol. Soc. Am.*, vol. xvi., 1905, p. 295.

[11] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1903, p. 259.

[12] F. Bascom, *l.c.*, p. 295.

The alkalies in the Red Clays form part of the composition of the zeolite crystals, which exist in enormous numbers, and are widely distributed, particularly in the pelagic clays and oozes. The proportion of potash and soda is 5 and 4 per cent. respectively. It is believed that these crystals may be derived from the alteration of volcanic material by the action of water, but this will be discussed in a later chapter. The figures above quoted probably represent about the maximum proportion of alkali in sedimentary rocks. It is absent in many instances, but this is also true of the igneous rocks, many of which contain no trace of either potash or soda, so that the average percentage would be about the same in the sediments as in the volcanic rocks.

Mineral Salts in Rock Systems.—Besides the quantity actually existing in the ocean clays and sedimentary rocks in general, there are particular instances where very large quantities of both potash and soda have been deposited in the form of rock salt. The Saline Series at the base of the Primary system in the Salt Range of India is from 800 to 1,500 feet in thickness, and contains a high percentage of both alkalies.[1] Salt in large quantities is also mined in rocks of about the same age in America. The early Secondary rocks of England, Germany, and Russia are particularly rich in mineral salts. The New Red Sandstone deposits of Stassfurt hold immense beds, 2,500 feet in depth, and the analysis shows that the proportion of potash to soda is 85 to 2 per cent.[2] The British salt mines are worked in strata of the same age, and the beds frequently aggregate 200 feet in depth. Rock salt is also obtained from the Tertiary system in India and Italy.

The unusual aggregation of these salts is due to chemical precipitation during periods of exceptional evaporation of the oceans, which have been frequent in the earth's history, and will be referred to in later chapters. At the same time, potassium is also an organic salt, and is found in many vegetable and animal substances. Wood contains small quantities. In the ash of good coal it forms 1·17 per cent., and the ash forms about one-eighth part of the coal, so that the total quantity of potash stored up in the coal measures of the world must be considerable. That is to say, the stratified rocks contain an abundance of the alkalies, and if melted would provide a sufficient quantity to make up the average of 3 per cent. in igneous rocks.

Mineral and Chemical Composition of Granite.—The alkalies combine with silica and form felspar in igneous rocks. Those rich in soda are termed Plagioclase or Albite. Those rich in potash, Orthoclase. Felspars also sometimes contain lime. If now we take a typical granite and examine its mineral content, its relation to the

[1] W. Wynne, "Geol. of Salt Range." *Geol. Survey India, Mem.*, vol. xiv., 1878, p. 80.
[2] T. E. Thorpe, *Dictionary of Applied Chemistry*, vol. iii., 1893, p. 265.

sedimentary rocks is at once evident. There is, however, an important difference between the two. The carbonate of lime in the latter is represented by lime in the former. The carbon dioxide, CO_2, has been driven off by heat from the $CaCO^3$, so that only the CaO remains as in the ordinary process of lime burning. A typical granite consists principally of quartz, felspar, mica, hornblende, or biotite in various combinations, together with a small proportion of less important minerals. Quartz in combination with any one or any two of these minerals might be termed a granite if in a crystalline condition through heat and pressure. The photo-micrographs, Plate II., Figs. 2 and 3, show two instances of such combinations.

The clear white masses D-E, 4-5 in both are Quartz, the cloudy grey crystals in A-B-C, 4-5 and D-E, 1-2 in both cases are felspars. In No. 1 the dark crystals, A, 2-3-4 and C, 2-3-4, are Biotite. The dark minerals in No. 2 are black Mica, but D, 2 is Hornblende, and A, 2-3 a crystal of Sphene or Titanite. The small rectangular prism in D, 2 is Apatite. The chemical composition of each of these minerals, and consequently of the granite, is set out in the following table :—

	SiO_2.	Al_2O_3.	Fe_2O_3.	TiO_2.	P_2O_3.	K_2O.	Na_2O.	F.	CaO.	MgO.
Quartz, . .	X	..	..	..	..	..	..	..	..	..
Mica, . .	X	X	X	..	..	..	..	..	..	..
Hornblende, .	X	..	X	..	..	..	..	..	..	..
Biotite, . .	X	..	X	..	..	..	..	..	..	X
Felspar, . .	X	X	..	..	..	X	X	..	..	..
Titanite, . .	X	..	..	X	..	..	..	..	X	..
Apatite, . .	X	..	..	..	X	..	..	X	X	..

That is to say, these samples contain practically all the chemical constituents of the sedimentary rocks.

Igneous Rocks and Sedimentary Origin.—We have now followed the sedimentary cycles through all the stages of evolution, from the original three-fold differentiation, through contortion, metamorphism, liquefaction, emission and recrystallisation, and the last state is seen to be definitely related to the first. The identity of the constituent minerals is never lost sight of, and although the final differentiation is not identical with the original, the resemblance is so close that the sedimentary origin of the igneous rocks appears to be placed upon a reasonable basis.

The chemical differentiation of the oozes upon the existing ocean floor, where the acidic sediments occupy the pelagic, the basic or less siliceous, the intermediate depths, and the ultra-basic or calcareous muds, the shallower water, corresponds with the different stages of continued volcanic eruption. The lavas revert to their original differentiation, so that throughout the whole of the sedi-

Fig. 1.—LEWISIAN GNEISS.

Differentiated bands of darker (basic) and lighter (acid) igneous rock. Contortions due to plastic deformation.

British Survey Photograph.

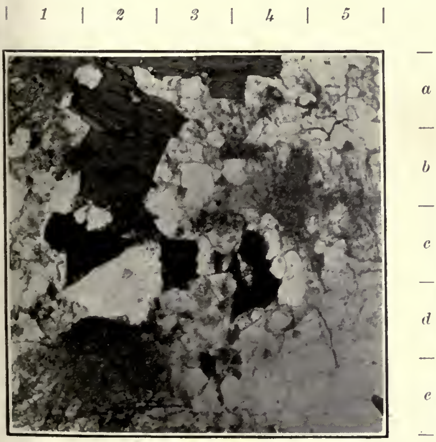


Fig. 2.

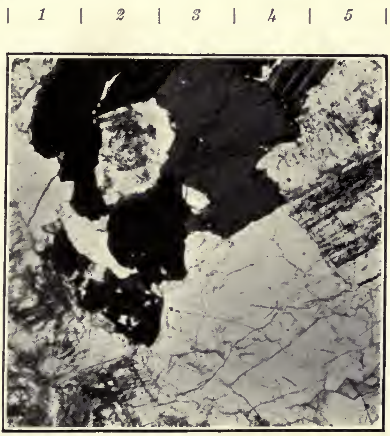


Fig. 3.

Photo-micrographs of granites showing mineral composition. Enlarged 20 diameters.

British Survey Photographs.

mentary systems the crystalline schists and down into the igneous magma; the acid, basic, and ultra-basic rocks continue to follow one another to the very interior. By the process of metamorphism, which only produces minor chemical changes, an acid ooze is converted into an acid rock, and this into an acid lava. Basic and ultra-basic oozes by similar means and stages produce corresponding lava flows.

The lavas and granites of the "volcanic cycles" were deposited in sedimentary systems, in the earliest ages of the earth's history, identical with those now being laid down. This is in accordance with the belief of geologists, who consider that molten rock outpoured upon the surface of the earth is derived at least in part from the melting of original earth substance [1] or sedimentary material.

For a long time it was thought by other geologists that the Plutonic rocks and the Crystalline schists were the original cooled crust of the earth, upon which the later sediments have been deposited in water. It has, however, been pointed out that "recent investigations render it extremely doubtful whether any accessible rocks can be referred to the supposed original crust," [2] and that the massive crystalline rocks, which might be so referred, is "reduced to an unknown, if not to a vanishing point."

The considerations dealt with in this chapter carry us a step further, and prove that none of these rocks represent an original cooled crust. Even the fiery magma within, if it had a continuous existence, owes its origin to aqueous sediments laid down in the bed of the Primæval ocean. The geological history of the world commences with the building up of sedimentary oozes in the abyssmal regions of a pre-Archean ocean.

[1] J. N. Le Conte, *Elements of Geology*, 5th ed., p. 227.
[2] T. C. Chamberlain and R. D. Salisbury, *Geology*, vol. i., 1905-6, p. 138.

CHAPTER VII.

THE ORGANIC ROCKS.

Organic Life in Oceans—Petrification of Organic Remains—Extent of Coral Formations in Modern Seas—Local Organic Sediments—Absence of Fossils in Devonian Red Rocks—Profusion in Mountain Limestone—Secondary and Tertiary Organic Rocks—Faunal Record very Incomplete—Evidence of Life in pre-Cambrian Oceans—Theory of Descent and Long Life Records.

PALÆONTOLOGY is the branch of science which treats with the succession of life which has existed from the remote ages of the earth's history down to recent times. The fossil forms of life which lived in many early periods, and are entombed in the rocks, are classified and described. The impressions they have left upon the sands of time are of the utmost service to the geologist in determining the relative age of the stratified beds, and placing them in chronological order. The record of the rocks would still be unwritten if these fossils were not preserved.

The Primary, Secondary, and Tertiary strata often retain memorials of the creatures which inhabited the oceans in which they were formed, but many of the rocks of these systems may be quite destitute of organic remains. Evidence of life in the older, pre-Cambrian sediments has almost entirely disappeared. As a rule, the older systems are generally more barren in this respect than the younger. It is the purpose of this chapter, however, to show that the absence of fossils is rather due to the metamorphic and other changes which have intervened since their formation than to the non-existence of life in the oceans in which they were deposited.

Organic Life in Oceans.—The manner in which the bed of the ocean is now being constructed is a guide to the causes which have produced the materials of which many mountains are built up.

During the cruise of the "Challenger" it was ascertained that "life in some of its many forms is universally distributed through the ocean, at all depths from the surface to the bottom. It is most abundant at or near the surface, and at or near the bottom. There do not seem to be any barren regions where life is altogether absent." [1] Diatoms, which are a microscopic form of vegetable life with sili-

[1] Sir J. Murray and Renard, *Challenger Reports : Deep Sea Deposits*, 1891, pp. 249, 250.

ceous frames, "becloud the waters of the Southern Ocean."[1] "At times they occur near the surface in enormous numbers, in great floating banks many miles in extent and several fathoms in depth." Many forms of animalculæ are present in similar abundance, among which are *Radiolaria* and *Globigerina*. The sea in all latitudes literally swarms with low forms of organic life.

The fertility of the seas may be gathered from the records of the voyage of the "Beagle." Darwin described large areas of the Pacific Ocean where the sea water was discoloured from organic causes. "Some of the water placed in a glass was of a pale reddish tint; and examined under the microscope was seen to swarm with exceedingly minute animalculæ, darting about and often exploding. One patch alone must have extended over several square miles. The colour of the water, as seen at a distance, was like that of a river which had flowed through a red clay district; but under the shadow of the vessel it was quite a dark chocolate."[2] Individually these tiny creatures required a powerful microscope before their existence was detected, but in their multitudes they were seen for miles.

As these organisms die, the calcareous tests of the foraminifera and the siliceous frustules of the diatoms and radiolarians sink to the bottom. They enter largely into the composition of the widespread oozes which are accumulating over vast areas of the sea bottom, and which were referred to in Chapter III. Throughout the Arctic, Temperate, and Equatorial regions of the ocean a constant rain of these sheaths is ever falling to the bottom, and beds of sediment are slowly accumulated.

The quantity of organic matter available in the sea for the building up of these sediments has been ascertained by experiment. Samples of the water from favourable spots have been taken, and it has been calculated that 51 tons of carbonate of lime in the form of shells of organisms will be held in suspension in a mass of ocean water 1 square mile in area and 100 fathoms in depth.[3]

Petrification of Organic Remains.—The animal and vegetable life of the ocean, engaged in the deposition of silica and carbonate of lime, is admirably suited for the building up of compact clays, which eventually harden into rock. The inorganic material forms the nucleus of the mass, and the organic tissues form a welding medium, which in time consolidate together. "On the death of the plant or animal, the jelly-like mass forming the slimy envelope loses part of its water, becomes cheese-like in consistency, and finally hardens into stone." In some cases it has been observed that, "at a depth of a foot or more, the organic substances are

[1] J. D. Dana, *Manual of Geology*, p. 143.

[2] C. Darwin, *A Naturalist's Voyage round the World*, p. 16.

[3] Sir J. Murray, "Coral Reefs and other Carbonate of Lime Formations in Modern Seas." *Nature*, June, 1890, p. 163.

entirely petrified and reduced to marble; at less than a foot from the surface they approach nearer to their natural state; while at the surface they may be alive, or if dead, in a good state of preservation."

Besides the rain of these shells from the surface waters to the bed of the ocean, large areas of the sea floor are being built up by reef-building corals. The coral polyps are near relatives to the sea anemone, and possess internal calcareous skeletons with soft cylindrical bodies, and usually live in colonies attached to one another and the rocks. It is the remains of these polyps, together with those of the free swimmers, which build up the floor of tropical seas. Gradually the accumulation reaches the surface and forms atolls and reefs. The limestone which is formed in this way is "fine-grained, compact, and as solid and flint-like in fracture as any Silurian limestone, and with rarely a shell or fragment of coral visible." [1]

Extent of Coral Formations in Modern Seas.—These creatures flourish best in Tropical seas. "There are enormous areas in the Pacific and Indian Oceans, in which every single island is of coral formation.[2] Thus the Radack group of atolls is an irregular square, 520 miles long and 240 miles broad; the Low Archipelego is elliptic-formed, 840 miles in its longer and 420 in its shorter axis, with other small groups, making a linear space of ocean actually more than 4,000 miles in length." The total area of the ocean bed being built up by coral mud is estimated to amount to no less than 2,700,000 square miles.

The reader of the "Challenger" Reports cannot but notice the small place taken by the bones and other remains of large vertebrates in the ocean muds. Their skeletons and teeth are rare, and contribute relatively little to the accumulation of these muds compared with the microscopic protozoa.

Local Organic Sediments.—More local formations, such as pools of stagnant water, which are not exposed to periodical drying up, are invaded by a peculiar vegetation, mostly composed of *Confervæ*, single thread-like plants of various colour and of prodigious activity of growth, mixed with a mass of *Infusoria*, animalculæ, and microscopic plants, which soon fill the basin and cover the bottom with a floating of clay-like mould. So rapid is the work of these minute beings that in some cases 6 to 10 inches of mud is deposited in a year. This becomes gradually thick and solid, and after a time the hollow is filled to the surface and is clothed with verdure.[3]

Organic Rocks in Primary System.—If now we turn to the stratified rocks which compose the principal sedimentary systems, we

[1] Sir J. Prestwich, *Geology: Chemical, Physical, and Stratigraphical*, 1886-8, vol. i., p. 240.

[2] Charles Darwin, *A Naturalist's Voyage round the World*, 1890, p. 497.

[3] G. F. Wright, *Ice Age in North America*, 1911, p. 595.

find records of a similar profusion of fauna which lived in the oceans of those periods. Since the earliest sedimentary rocks are so barren of organic remains, it is convenient to commence at the base of the Primary system, where the evidence is clear, and afterwards return to the older ones.

Immediately we leave the zone of the pre-Cambrian systems, the richness of the fauna distinguishes the younger rocks from the older. "Trilobites swarmed in the early seas of Lower Cambrian age, and in some cases sponges cover almost the whole surface of the beds." In the next section, "some layers of the Lower Silurian are perfectly loaded with fragments of Trilobites, which serve to show the exceeding richness of the ancient fauna." The endless supply of beautiful fossils in the quarries of the Wenlock shales of Dudley, which belong to the Upper Silurian, is a wonderful scene of the profusion of life during that early geological period.

The forms of life which tenanted the seas in Cambrian and Silurian time are so similar, that they may be considered together in a brief summary. Some species do not make their appearance until the beds of Lower Silurian age are reached and the later deposits are richer in fossil remains.

The kingdom of the Protozoa is represented by sponges, *Radiolaria*, and *Foraminifera*. Polyps, star fishes, sea urchins, and sea lilies were very abundant. Worms and barnacles have also left traces of their existence in the burrows they made in the sands and clay. Trilobites attained their greatest zize in Cambrian times, and their widest distribution in the Silurian seas. Shell-bearing mollusca, such as ammonites, cuttlefish, univalves, lampshells, and bivalves, inhabited the ocean bed. Bivalves and ammonites occupied a particularly important place.

Radiolaria were important rock-forming organisms while the Primary rocks of New South Wales were being built up. Many thousands of feet of strata are composed chiefly of the tests of these microscopic organisms, which permeate the bulk of the rock at the rate of about one million to the cubic inch.[1]

As an additional link between the past and present, "reef-building corals attained a great development in the earliest seas, and were perhaps more widely diffused, and individually abundant in Silurian ages, than any subsequent period."

Absence of Fossils in Devonian Red Rocks.—When we approach the Devonian and Old Red Sandstones of the succeeding series, a great decrease of fossil remains is apparent. This curious circumstance will be again referred to. There is evidence that the seas were still well stocked, and that new forms of life made their appearance. A remarkable species of vertebrate is the most notable of these. It was distinguished by the peculiar form of its

[1] T. W. Edgeworth David and E. F. Pittman, "Radiolarian Rocks of N.S.W." *Quart. Journ. Geol. Soc.*, 1899, p. 36.

head and tail. The upper lobe of the tail was much larger than the lower, and the head was broad and flat. Both these peculiarities show that its habitat was either in or upon the mud of the ocean bed. The later free-swimming varieties have the lobes of the tail equal.

Profusion in Mountain Limestone.—As soon as the region of the Mountain Limestone is entered, the fauna again increases in importance. "The deposits of this age point to a clear and moderately deep water," where a prolific marine fauna gradually built up masses of limestone hundreds, or even thousands, of feet in thickness. Those which to the naked eye appear destitute of fossils and structureless, may be shown by the examination of thin slices of them under the microscope to be crowded with organic remains, both entire forms of *Foraminifera*, *Radiolaria*, and spicules and fragments of larger kinds." [1] About three-quarters of the entire surface of Ireland is built up of rocks of this age. "This great calcareous formation consists almost entirely of the shells and skeletons of marine animals, such as corals, crinoids, foraminifera, and molluscs. Even the denser masses are sure to show a field full of animal forms." [2]

Plate III. gives illustrations of the organic structure of rocks. Fig. 3 shows a section of Carboniferous limestone under the microscope. It is wholly composed of the fragments of calcareous shells of a variety of marine organisms. These include foraminifera in great plenty, several of which are prominent, crinoid stems, one of which is seen in section, brachiopods, polyzoa, corals, and gasteropods. Most of these have suffered fragmentation and partial solution, but the small shells of the foraminifera are often perfect. Fig. 4 is composed of a confused aggregrate of bryozoa, foraminifera, a few shell fragments, and quartz grains set in a matrix of granular calcite. The other figures explain themselves.

Secondary and Tertiary Organic Rocks.—The later rock systems preserve a similar record. In the chalk, for instance, which forms the massive cliffs of the south coast of Kent and Sussex, "when we wash some, and look at it with a microscope, we see a fine white paste, in which myriads of little shells, so small that two or three million would go into an ordinary thimble. We may also find in it the remains of corals, scallops, sponges, cockles, lamp shells, cuttlefish, star fish, sea urchins, seaworms, lobsters, various fish and sharks; many sea reptiles, turtles, and flying lizards, etc." [3]

The Nummulite limestone of Tertiary age is almost entirely composed of *Foraminifera*. It plays a far more conspicuous part than any other Tertiary group in the framework of the earth's crust.

[1] Sir A. Geikie, *Text-book of Geology*, 4th ed., 1903, p. 1041.
[2] E. Hall, *Physical Geology and Geography of Ireland*, 2nd ed., 1891, p. 52.
[3] E. Westlake, *Outline of Geol. of Fordingbridge*, 1889, pp. 3-5

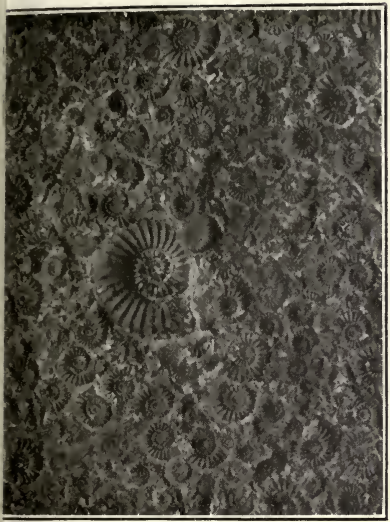


Fig. 1.—Marston Stone with Ammonites from the Lias, Yeovil, Somerset. × $\frac{1}{4}$.

Fig. 2.—Orthoceras Limestone. Upper Silurian of Bohemia. × $\frac{1}{10}$.

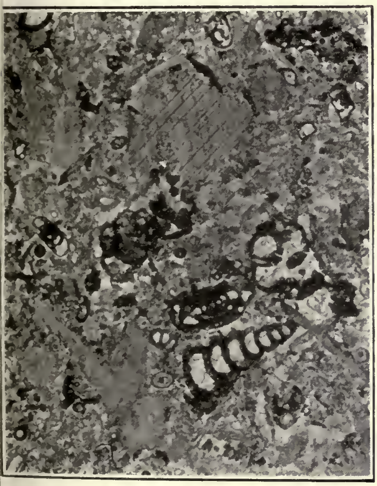


Fig. 3.—Carboniferous Limestone. × 15.

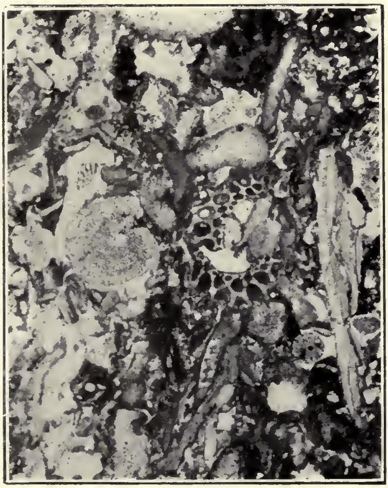


Fig. 4.—Doulting Stone. Jurassic. × 15.

British Survey Photographs.

Scale linear.

It often attains a great thickness, and extends from the Alps to the Carpathians, Algeria, Morocco, Egypt, Asia Minor, Persia, India, and Bengal to the frontiers of China.[1]

Infusorial earth has been obtained from some ancient rocks, as well as from the deposits of modern waters. It consists of the remains of one-celled Diatoms, which, when viewed under the microscope, are seen to have curiously formed bow-shaped and rounded transparent bodies, which consist of pure silica or flint, and are the coatings which strengthen the cell walls. At Bilin, in Bohemia, there is a single stratum, 14 feet thick, forming the upper layer of a hill, in every cubic inch of which there are 40,000,000 units of *Infusoria*. There are also extensive beds of this earth in America, covering many square miles in area and from 40 to 300 feet thick.

Faunal Records very Incomplete.—During the Secondary, Tertiary, and Quaternary ages the larger reptiles and mammals lived in great numbers in the sea and upon land, but, like their modern equivalents, their remains form quite a small proportion of the quantity of fossilised animals and fish which are preserved in the strata of those systems.

The richness of organic remains stored up in the rocks is not uniform through their whole depth. Many may be carefully searched without the discovery of a single specimen. "The absence of fossils in the earlier strata does not, however, indicate the non-existence of living beings at the time they were deposited, but the rocks have been so metamorphosed that the fossils have been destroyed."[2] "Whole tribes of animals, which were almost certainly represented in Cambrian Seas, have entirely disappeared."[3] It is indeed remarkable that so many have been preserved when the length of time and the influences tending to their destruction are taken into consideration. "As soon as a plant or animal, or any part of either, is buried in sediment, it becomes subject to decomposition. Even the harder and more durable parts undergo some change, and may eventually become disintegrated and entirely disappear."[4] Abundant as the remains are, they do not adequately portray the profusion of aquatic life which has inhabited the oceans of the distant Cambrian and later epochs down to recent times.

Evidence of Life in pre-Cambrian Oceans.—It is generally correct to say that the older and deeper the rocks are, the more and more barren of organic remains they become. The pre-Cambrian sediments are almost devoid of fossils, while the Fundamental Complex is entirely so. Where evidence is lacking, analogy has to be appealed to, to assist us in probing the mystery of the past.

[1] Sir C. Lyell, *Elements of Geology*, 6th ed., 1865, p. 305.
[2] Baron Avebury, *Scenery of England*, 1902, p. 13.
[3] Sir A. Geikie, *Text-book of Geology*, 4th ed., 1903, p. 910.
[4] James Geikie, *Structural and Field Geology*, 2nd ed., 1908, p. 88.

It has been suggested that the graphite and limestone of the Laurentian highlands of Canada and kindred rocks of other parts of the world, indicate the earliest existence of life. "There are traces of vegetable tissues, probably fucoidal, in the graphite and graphitic shales of New Brunswick."[1] Such early vegetable remains are "probably due to sea weeds or algæ."[2] Other writers consider that their position, so low down in the scale, is the result of later igneous intrusion, although the means whereby this has been accomplished is not apparent. For many years the limestone was supposed to owe its origin in part to an early species of Foraminifera, to which the name *Eozoon* was given, but later investigation has thrown doubts upon the organic nature of the structure. It is now thought to be due to infiltration, so that neither the graphite nor the *Eozoon* can be relied upon as proof that life existed at this early age.

There are other indications that the pre-Cambrian ocean was not devoid of life.

"Now and again, evidences of organic life are found in these ancient schists, such as worm burrows, sponge spicules, and traces of *Algæ* or *Protozoa.*"[3] In some shales of Montana, at a depth of 7,700 feet, and again at 10,000 feet, from the top of the series, four specimens of annelid trails have been found, with worm burrows, and thousands of ill-preserved crustacean fragments that appear to be early forms of Merostomata.[4]

The upper Torridonian shales contain occasional phosphatic lenticels, which, under the microscope, are seen to contain fibrous tissue. "It seems impossible to avoid the conclusion that these peculiar structures are of organic origin."[5] Worm burrows and other fossil remains, which are supposed to be organic, have been discovered in the Upper Huronian of Newfoundland.[6]

The evidence of life in these early ages is strengthened by the actual discovery of fossils, and is further confirmed by the nature of many of the rocks immediately overlying the igneous complex. The cherty and ferruginous rocks, at the very base of the pre-Cambrian series in the Lake Superior region, are similar to much more recent ones, and are, therefore, believed to be of organic origin.[7] This also applies to the jasperites, which are of frequent

[1] Sir J. W. Dawson, *Acadian Geology*, 4th ed., 1891, p. 631.

[2] Sir J. Prestwich, *Geology: Chemical, Physical, and Stratigraphical*, 1886-8, p. 22.

[3] Sir J. W. Dawson, *Acadian Geology*, 4th ed., 1891, p. 663.

[4] C. D. Walcott, "Pre-Cambrian Fossiliferous Formations." *Bull Geol. Soc. Am.*, vol. x., 1899, p. 206.

[5] B. N. Peach and Associates, "The Geol. Structure of the North-West Highlands." *Mem. Geol. Survey Gt. B.*, 1907, p. 288.

[6] Sir J. W. Dawson, *Acadian Geology*, 4th ed., 1891, p. 88.

[7] R. D. Irving and C. R. van Hise, "The Penokee Series of Michigan and Wisconsin." *U.S. Geol. Survey, Tenth Ann. Rep.*, part 1, 1888-9, p. 368.

occurrence in the pre-Cambrian series, as well as in the Upper Laurentian sediments.[1] The limestones of the Grenville series of Ontario often contain the original organic pigments.[2] Thus limestone, carbonaceous shales, and iron formation extend to the very bottom of the known geological column, and suggest the existence of life in the earliest rocks.[3] There is every reason for supposing, therefore, that marine life has existed in great profusion from the earliest ages of the sedimentary record.

Theory of Descent and Long Life Records.—The fossilised relics of the life of that far distant age yet discovered are comparatively few, but as the Cambrian rocks immediately above them yield so rich a record, "the fossils of this horizon must unquestionably have had a long series of ancestors, though of these still earlier forms such slight traces have been found."[4] The fauna at the base of the Cambrian is abundant and varied. It includes all the stems of the animal kingdom except the vertebrates. Some geologists say that nine-tenths of the differentiation had taken place at the beginning of Cambrian time.[5] From the general character of this early fauna it must be regarded as certain that life had existed for a long series of ages before that fauna appeared, in order that such well-advanced grades of organisation should then have been reached. Since the largest known trilobite has come from the base of the Cambrian system, "the adherents of the theory of descent argue the strong probability of the occurrence of organic remains in these ancient pre-Cambrian rocks." "If this theory be true, it is indisputable that before the lowest Cambrian stratum was deposited, long periods elapsed, as long as, or probably far longer, than the whole interval from the Cambrian age down to the present day, and that during those vast periods the world swarmed with living creatures."[6]

It is now possible to take this argument to a much greater extreme. The crustacea of the Montana shales so far below the base of the Cambrian are probably more highly organised, and perhaps had a more venerable ancestry even than the Trilobite. If the cell was the first form of life then it probably preceded the earliest known crustacean by many millions of years, but the cell is supposed to be a successful form of organism, and probably stands removed by a million years of evolution from the simple living material which first took shape.

[1] H. W. Fairbanks, "Geol. of Californian Coast Ranges." *Bull. Geol. Soc. Am.*, vol. vi., 1894, p. 85.

[2] F. D. Adams and A. E. Barlow, "The Geol. of the Haliburton and Bancroft Areas of Ontario." *Geol. Survey of Canada, Mem.*, vol. vi., 1910, p. 221.

[3] C. R. van Hise and C. K. Leith, "The pre-Cambrian Geol. of North America." *U.S. Geol. Survey, Bull.* 360, 1909, p. 20.

[4] Sir A. Geikie, *Text-book of Geology*, 4th ed., 1903, p. 910.

[5] C. R. van Hise and C. K. Leith, "The pre-Cambrian Geol. of North America. *U.S. Geol. Survey, Bull.* 360, 1909, p. 34.

[6] Charles Darwin, *Origin of Species*, 6th ed., vol. ii., 1888, p. 83. Sir E. Ray Lankester, *Extinct Animals*, p. 276.

We see from the facts recorded in this chapter the probability that life has existed on our planet through all the ages of its history, and that the fossil remains of the organisms have played a not inconsiderable part in the building up of the earth's crust. The purpose of the next chapter is to show that, long as the record of life is, and clearly as its records are preserved, the important place that the microscopic protozoa have taken in the constructive processes has never been adequately granted. The effectiveness of vital force in the production of matter is a subject which has not received the attention it deserves.

CHAPTER VIII.

ORGANIC CYCLES.

The Absence of Fossils in Red Deposits—The Origin of Red Clays discussed—Red Clays not Mechanically Derived—Red Clays not Chemical Precipitates—Not Decomposed Volcanic Material—Red Clays and Transported Fragments—Red Clays and Decomposition of Underlying Rocks—Organic Origin of Red Clays—Absence of Fossils due to Chemical Changes—Constant Differentiation due to Organic Causes—Rocks Primarily of Organic Origin.

THE similarity in order of deposition, in chemical composition and in colour, of the ancient rock systems, which proves their sedimentary character, is an equally valuable guide to the cause of sedimentary differentiation. The siliceous deposits now forming in the deepest parts of the ocean are almost entirely of organic origin and composed of the remains of Radiolaria and Diatoms. The calcareous oozes of shallower water consist of the tests and sheaths of lime-secreting Foraminifera. The red clays, occupying the intermediate depths, are, practically, unfossiliferous. Passing from the red clay levels into shallower water an organic calcareous bottom is encountered, while in descending into the abyssmal hollows the surrounding bed is a siliceous deposit of similar origin.

Absence of Fossils in Red Deposits.—The absence of organic remains in the Red Clays is not peculiar to the oozes of the present ocean, but is noticeable in certain of the older sedimentary rocks. The barren mudstones of the Cambro-Ordovician system in Scotland are intermediate between the Radiolarian Cherts and the limestone member of the cycle, and other instances might be quoted.

Frequently, in the Primary rocks, "as soon as the Red Strata begin, the organic remains rapidly die out, until at last only the fish and the larger crustaceans continue to occur."[1] From the Silurian upwards we have to pass through some 4,000 feet, more or less, of barren red sandstone and marls, until we again encounter a copious marine fauna in the Carboniferous limestone.[2] "For many years the Old Red Sandstone was regarded as very barren of organic remains, and such is undoubtedly its characteristic over very wide areas, where calcareous matter is wanting, and where its colour is determined by the red oxide of iron."[3] This is equally true of the

[1] Sir A. Geikie, *Text-book of Geology*, 4th ed., 1903, p. 936.
[2] *Ibid.*, p. 981.
[3] Sir C. Lyell, *Elements of Geology*, 6th ed., 1865, p. 520.

Secondary red chalk [1] and the red deposits in the Tertiary system of New Mexico.[2]

The "Challenger" Reports make similar comments upon the Red clays of the present ocean bed. "It is a remarkable fact that we do not find in these red deposits a trace of the green-coloured glauconite casts of *Foraminifera* and other calcareous organisms. There are a few spicules of siliceous sponges, but frustules of Diatoms, and the remains of Radiolarians are exceedingly rare or wholly absent." [3] This phenomenon is clearly shown in the analysis of the deposits. One sample of deep-sea sediment of Radiolarian origin "was estimated to be made up of 80 per cent. of the remains of siliceous organisms." [4] At less depths it was not so pure; 54 per cent. of silica is about the average. The percentage of carbonate of lime in the shallower oozes gives about the same proportions. It increases as we pass upward towards the 1,000-fathom line, where it amounts to as much as 70 per cent., and 90 per cent. at 400 fathoms. The proportion of fine washings in each case is quite small, whereas in the Red clays this constitutes from 80 to 90 per cent. of the whole.

The Origin of Red Clays Discussed.—The origin of these Red Clays, barren as they are of organic remains, has an important bearing upon the cause of differentiation which is so constant in all the rock systems. If they are produced by processes other than organic, and consequently have a different origin than the oozes which graduate into them in shallower and deeper water, then the same processes have been in operation in past geological ages for the formation of the rocks which are similar to them in every respect, save the alteration which they have endured. If, on the other hand, it is reasonable to suppose that they are primarily of organic origin, although traces of this are so largely absent, then the determination of the cause of sedimentary differentiation is much simplified.

If we first enumerate the possible causes of their formation, then by the process of elimination of the improbable ones, we may arrive at the most probable.

They may be due (1) to the disintegration of the older rocks of the visible earth, the particles of which were floated out and rearranged in the form of impalpable dust; (2) to the precipitation of chemical matter held in suspension or solution in the water; (3) to volcanic dust erupted upon the sea floor or carried for great distances in air or ocean currents until it settled; (4) decomposition *in situ* of rocks similar to themselves in composition; (5) to the same

[1] J. W. Judd, "Observations on the Neocomian Strata of Yorkshire." *Quart. Journ. Geol. Soc.*, vol. xxvi., 1870, p. 328.

[2] E. E. Howell, *Geol. of Portions of Utah, Nevada, Arizona, and New Mexico*, 1875, p. 276.

[3] Sir J. Murray and Renard, *Challenger Reports: Deep Sea Deposits*, 1891, p. 234.

[4] *Ibid.*, p. 205.

organic causes to which neighbouring oozes are undoubtedly due, with subsequent alteration.

Red Clays not Mechanically Derived.—1. It is an axiom of geological deduction that strata formed of detrital matter brought from the land into the sea or lakes are thicker and coarser towards the shore line, and thin out and are finer towards deeper water, while ocean deposits thicken towards the deep and thin out in shallower water. The detrital sediments graduate in thickness in exactly the opposite direction to the oozes. As silt-laden currents lose velocity and disappear in the greater volume of the ocean or lake, their power of holding heavier matter in suspension diminishes with the velocity, so that the greater quantity, as well as the larger particles of sand, fall first, and only the finest silt finds its way to any great distance.

If we compare this with what is going on in the ocean, the law does not apply beyond very limited distances from the continental shore lines. Along the margins of the land, and beyond the region of marked tidal action, the sea bed consists very largely of the products of land erosion, which are carried into the sea by rivers and streams, and distributed by waves and tidal currents. But there is an absence of the phenomena due to this cause below 600 feet, and within this region the particles are larger, and form the greater percentage of the deposit near the shore. The Greensand marks the boundary between the products of erosion which follow this law and the true ocean muds. Beyond the terrigenous muds we pass first into the Calcareous areas, so that a deposit essentially of organic origin separates the detrital sediments from the inorganic red clays, which shows that there is no connection between them as far as origin is concerned. Even if they were not separated in this way, the distinction between the terrigenous deposit and pelagic ooze is clear, since the percentage of fine washings, as distinct from the shells of organisms, increases with the depth in one case and decreases with the depth in the other. From 2,000 to 2,500 fathoms in the Red Clays it amounts to 80 per cent., from there to 3,000 it is 85 per cent., and down to 3,500 fathoms it increases to 95 per cent., which would be reversed if they were the products of land erosion.[1]

If these clays have indeed been brought into the depth of the ocean by mechanical means, and other forces have come into play to account for these differences, then the Calcareous oozes have also been derived from similar sources, but they are admittedly of organic origin. Besides this, it has been ascertained that no coast detritus reaches the red clay areas.[2]

The detrital origin of the Red Clays appears even less probable

[1] Sir J. Murray and Renard, *Challenger Reports: Deep Sea Deposits*, p. 193.

[2] Sir J. Murray, "On the Distribution of Volcanic Debris over the Floor of the Ocean." *Proc. Royal Soc. Edinburgh*, vol. ix., 1878, p. 260.

when the specific gravity of the various oozes is compared. The specific gravity of carbonate of lime is 2·7, the silicates of alumina, iron, and manganese rise as high as 3·5, while that of silica is 2·6, and of organic silica 2·3 to 1·9. If all these muds are of secondary detrital origin, they would be distributed according to their specific gravity. The heaviest would be nearest the shore, and would be followed by slow gradation into the deepest abysses, where the lightest would be. Instead of this being the case, the Red Clays are the heaviest, and generally further from the shore than the Calcareous oozes.

Red Clays not Chemical Precipitates.—2. So far, we have considered the geographical distribution of the oozes, but when the oceans, as has been the case in past geological epochs, become filled with great depths of deposit, the silica, the silicates, and the carbonates will follow one another in vertical sequence as they do in the older rocks. Even here the law of gravitation is contradicted in the same way as before. The lightest material is at the bottom, the heaviest in the middle, and the intermediate at the top. The percentage of silica increases with the depth, and at the same time the specific gravity decreases, which is the opposite to what we should expect if the muds were chemical precipitates.

The following table shows the decrease of the specific gravity of rocks in which the percentage of silica increases. The actual density may be affected somewhat by age and type of rock selected, but the relative variation would not be altered in this way :—

Per cent. of SiO_2.	Sp. Gr.
34,	3·14
39,	2·9
43,	2·75
68,	2·6

The apparent contradiction of the law of gravitation in the ocean deposits is further corroborated by the following circumstances :—If granite is melted in a crucible, the more siliceous and lighter constituents gather above those containing a greater proportion of alumina, iron, and alkaline earth,[1] and thus become partially differentiated in the same way that the minerals in a molten magma are believed to be arranged under the influence of gravity.[2] In the ocean exactly the opposite takes place, the more siliceous are in the deepest parts. The Calcareous rocks which surmount each series are heavier than the quartz which forms the foundation. In a glass works the surplus lime collects at the bottom of the crucible. In the ocean oozes it is at the top.

Red Clays not Decomposed Volcanic Material.—3. The "Challenger" Reports suggest that the Red Clays may be due to the

[1] Sir A. Geikie, *Text-book of Geology*, 4th ed., 1903, p. 407.
[2] A Harker, *Nat. Hist. Igneous Rocks*, 1909, p. 312.

decomposition of volcanic matter locally ejected in the bed of the ocean, and similar dust brought from long distances in the atmosphere. The typical Red Clays are, however, only in process of formation in particular latitudes and within particular depth limits, and, besides, are uniformly of basic composition. No geologist of to-day would seriously entertain the contention that the eruption of uniformly basic material would be confined to just those areas and just those depths. It is also equally unlikely that they would be erupted in this way over the enormous area occupied by the clays, and be relatively absent from the equally large areas of the Calcareous oozes. Vulcanicity is always local, but is also common to the whole globe, from the Behring Sea to the Equator, and produces in every case acid, basic and ultra-basic material. The restriction of submarine vulcanicity to the production of one uniform type of lava, as well as to the prescribed limits of the red clays, would be a phenomenon doubly unique and without precedent in the whole of the earth's history, as far as it is known.

Volcanic dust carried through the air is an equally unlikely cause. "In deeper water further from volcanic islands, the mineral particles which may be attributed to this source become less abundant and smaller."[1] The inorganic residue, of which the Red Clays are so largely composed, is disseminated throughout the Calcareous oozes, and gradually increases in proportion with the depth and distance from shore until it forms the bulk in the typical areas, so that it contradicts the ascertained results of wind-borne volcanic dust, although there are traces of this in all deposits.

Red Clays and Transported Fragments.—Considerable quantities of rock particles have been recovered from the ocean bed at all depths. Some of these have been carried from Northern latitudes by icebergs, others are fragments of pumice from volcanic sources, which have floated for a time, and have ultimately found their way to the bottom, while again others are more directly due to volcanic agencies.

These are the fragments which are believed to decompose during the formation of the Red Clays, but instead of being of the uniform basic composition required by this theory, they are of great variety, and include basalt, limestone, biotite, granite, gneiss, and others. Such a variety of rocks would scarcely produce a uniformly basic clay. The quantity of these fragments lying upon the ocean floor is probably wholly inadequate to account for this formation.

If the present condition of many of the rock particles, which have lain for long periods upon the ocean bottom, is examined, it is equally unfavourable to the decomposition theory. They usually become coated with oxides of iron and manganese, which is deposited in successive bands upon their outer surface, until the size of the

[1] Sir J. Murray and Renard, *Challenger Reports: Deep Sea Deposits*, 1891, p. 240.

concretion is out of all proportion to the original nucleus. The manganese will find its way into the worm holes in hard mud, and fills the cavities in the foreign matter around which it spreads. Any solid body suffices for the support of the concretionary deposit, and whether this is a fragment of rock or bone, the result is the same, and there is no chemical relation between the manganese and the nucleus,[1] which often retains its original outline, although it is sometimes entirely replaced by the manganese.

If the Red Clay were derived from these fragments, it is probable that there would be some chemical relationship between it and the rocks from which it was derived. The process of decomposition would, at the same time, obliterate all trace of the original, but this has not taken place in many instances, and the nuclei are relatively little altered. They have been preserved by the coating of oxide. It has also been ascertained that the concretions are characteristic of the Red Clay, and that the manganese is derived from it.[2] The oxides in the clays concentrate upon the nodules. The oxides of iron and manganese cannot at one and the same time be derived from the decomposition of the particles upon which it concentrates, and from the red clays. If the clay provides the concretionary substances which gather round the nuclei, it is not derived from them. The fact that bone is equally serviceable as rock debris, as a nucleus, points in the same direction. In the same way, the fragments of bone do not produce the oxides; they acquire it.

Red Clays and Decomposition of Underlying Rocks.—4. If it were conceded that the clays are the result of the decomposition *in situ* of basic rocks, it must at once be admitted that a quarter of the globe's entire surface[3] is uniformly covered by the same class of rocks, lying in beds conformable to the surface of the ocean bed, whereas in a minute area, such as the British Isles, nearly every rock system of the earth's crust is represented, each of which contains acid, basic, and ultra-basic rocks in infinite variety. Again, if these clays are the result of decomposition of older and more durable metamorphosed or volcanic rocks, we may ask why it is that the delicate shells of the siliceous and calcareous organisms in deeper and shallower water have so far escaped that action. Moreover, the decomposition of the visible rocks is due to the chemical and mechanical action of atmospheric agencies. The sea covering protects the ocean bed and preserves it from these destructive agencies. Timber, which is much more subject to decay than rocks, will last for an almost unlimited time if kept entirely submerged, so that there is little reason for supposing that decomposition has produced these clays, even if it were possible to suppose that the required basic rocks were as uniformly distributed as the clays.

All these suppositions are, therefore, very improbable explana-

[1] Sir J. Murray and Renard, *Challenger Reports: Deep Sea Deposits*, p. 366.
[2] *Ibid.*, p. 376. [3] *Ibid.*, p. 202.

tions of the origin of the clays, and it remains to discuss the probability of their organic origin.

Organic Origin of Red Clays.—5. The Red Clays are only distinguishable from the Radiolarian oozes by the relative absence of organic remains, which are generally absent in typical red clay, but may form as much as 60 per cent. of it. The Radiolarian ooze is essentially an organic deposit, as its name implies. The organic remains make up as much as from 60 to 70 per cent. of its composition, and the percentage of siliceous organisms generally increases towards the greater depths as the Calcareous ones do towards the shallower. The fine washings in the Radiolarian oozes sometimes consist very largely of shell fragments, whose original form cannot be determined, and appear to represent an intermediate stage between the organic ooze and the inorganic Red Clay, which strongly suggests that the latter were originally organic. The fact that the red clay is dispersed in varying proportions throughout the *Globigerina* ooze, which is essentially an organic deposit, points in the same direction.

Sir Wyville Thomson originally concluded that the Red Clays were not an additional substance introduced from without and occupying certain depressed regions, on account of some law regulating the deposition, but that they were produced by the removal by some means or other over those areas of the carbonate of lime, which forms the bulk of the materials of the *Globigerina* ooze. We may trace, he said, indeed every successive stage in the removal of it, in descending the slopes of a ridge or plateau where *Globigerina* ooze is forming, to the region of the Red Clays.[1] As the Calcareous shells disappear, the Red Clay increases. His view that these clays are primarily of organic origin was supported by Prof. Huxley [2] and Dr. W. B. Carpenter,[3] but since this requires that calcareous organisms contain silicates of alumina, which apparently they do not,[4] the conclusion is scarcely tenable upon those grounds.

On the other hand, however, it is in precisely those areas where the calcareous organisms disappear that the siliceous ones begin to appear. It is still probable, therefore, that the clay is of organic origin, and that both siliceous and calcareous organisms have contributed to its formation. The lime may, as has been suggested, have been removed by the sea water during the journey from the surface to the bottom, and that the aluminous residue has been silicified by commingling with the organic silica upon the bottom. Silica is well known to be a most powerful agent in producing

[1] Sir Wyville Thomson, F.R.S., "Notes on Nature of Sea Bottom." *Proc. Royal Soc.*, 1874, p. 45.

[2] Rt. Hon. T. H. Huxley, *Manual of the Anatomy of Vertebrate Animals*, 1877, p. 86.

[3] Dr. W. B. Carpenter, "Remarks on Prof. W. Thomson's Notes" above. *Proc. Royal Soc.*, 1874, p. 234

[4] Sir J. Murray and Renard, *Challenger Reports: Deep Sea Deposits*, p. 190.

secondary crystallisation, and it may even be possible that its action has effected the obliteration of the shells, to which it owes its own origin, and in the process has produced the variety of silicates which occupy this part of the ocean floor.

This conclusion is further supported by the fact that the water of the oceans swarm with life above the pelagic, the deep, and shallow seas. "The shells of surface formanifera must fall in equal numbers upon the Red Clay zones," as in the Calcareous zones.[1]

Absence of Fossils due to Chemical Changes.—The peroxide of iron, which is present in considerable quantities in all these clays, is detrimental to the preservation of organic remains, and may play some part in the process of decomposition. In the older rocks the presence of this mineral is supposed to indicate an organic product, so that some of the organisms may secrete those minerals which account for their own decomposition after deposition.

Carbon dioxide is the principal food of the *Diatomacea*, and the *Radiolaria* live in social union with small algæ, which also feeds upon it. This gas is distributed in greatest quantities in the deeper water, and acts powerfully as a solvent of carbonate of lime, so that the food of the vegetable organisms which build up the pelagic oozes is detrimental to the preservation of the calcareous shells of the animalculæ which fall from the surface and prevent the accumulation of carbonate of lime in the pelagic depths.

The required environment of the oceanic protozoa, the chemical action during the journey to the bottom after death, and secondary mineralisation after deposition upon the bottom, all have some influence upon the resultant deposit, and contribute some part to the final differentiation of the oozes.

Constant Differentiation due to Organic Causes.—The balance of probability indicates that the clays are of organic origin, and that foreign matter forms a not inconsiderable portion of the whole. No mechanical or secondary cause will satisfactorily account for all the conditions. Even if the wind-borne volcanic dust, the current-borne detrital matter from the land, cosmic particles, and all other foreign matter could be proved to form as much as 50 per cent. of the Red Clays, the constant differentiation of the older systems proves that those same processes have been in operation in all past ages. But this constant three-fold differentiation stamps it as original, and that although since the laying down of the very first cycle, secondary causes have played a greater and greater part in building up of sediment, yet the differentiation being original, is due to organic causes. The building up of these deposits in this peculiar manner is essentially a masterpiece of what we might term organic art.

Rocks Primarily of Organic Origin.—The organic derivation of

[1] Sir Wyville Thomson, "Notes on Nature of Sea Bottom." *Proc. Royal Soc.*, 1874, p. 44.

the primitive rocks, which is suggested from their analogy with the oozes of the present ocean, is further supported by the conclusion that has been come to regarding the origin of the quartzites, red grits, and dolomites, composing the Cambro-Ordovician cycle, which was taken as a type section for the older sedimentary rocks. The main part of that thick series of deposits appear to be derived from calcareous and siliceous organisms, and of the animals which fed upon the rain of the organisms which fell upon the bottom.[1] The obvious similarity between this cycle and that of the present ocean, on the one hand, and the systems composing the more ancient pre-Cambrian terrains, on the other, points to a common origin for them all.

Three-fold series of siliceous, red, and calcareous oozes are, therefore, built up by the lowly organisms of the deep. The differentiation is due to some fundamental endowment or habit of the various kinds of animalculæ which inhabit the oceans. The sedimentary cycles now become organic cycles, and since they are repeated again and again throughout all ages of the earth's history, even down to the molten interior, all these cycles are primarily of organic origin. Where the organic structure is not apparent from observation, it has been obliterated by heat or other metamorphic processes.

The chemical composition of the granite specimens described on p. 62 suggests that the rocks they represent were derived by the fusion of sediments of organic origin. The organic character of the silica, lime, iron, and alumina has already been discussed. The remaining mineral is Apatite, which is practically identical in chemical composition with phosphate of lime, P_2O_3 and CaO, and this again is the principal constituent of animal bone, so that in this sample we may have the crystalline equivalents of oceanic siliceous and calcareous protozoa, vertebrates and vegetation, all divisions of the living kingdom having contributed to its composition.

It, therefore, appears to be a logical and reasonable deduction from all the facts of the case, so far discussed, that these microscopic Protozoa have been the prime agents in the formation of the rocks of the earth's crust, from the Plutonic and Volcanic bosses, dykes, and lavas of the deep interior, through all the geological ages down to the present time. This important conclusion is based upon the scanty, although direct, evidence of the organic remains in some of the ancient rocks themselves, together with the reasoning from the theory of descent, and the equally conclusive deductions from analogy, as well as the fact that many rocks are shown to be almost entirely of organic origin. It is also in strict accord with the principles discussed in the opening chapter.

[1] B. N. Peach and Associates, "The Geol. Structure of the North-West Highlands of Scotland." *Mem. Geol. Survey Gt. B.*, 1907, p. 370.

CHAPTER IX.

THE FOUNDATIONS OF THE EARTH.

Commencement of Earth Building—Protoplasm and Vital Force—Function of Chlorophyll—Protoplasm and Environment—Original Minerals not Essential—Living Organisms as Chemical Agents—Architecture of Earth's Crust—Laurentian System Built-up—Effects of Accumulation of Strata—Metamorphic Phase—Volcanic Phase—Plutonic Phase—Oceans and Preservation of Crust—Fundamental Complex not a Separate Unit—Sedimentary, Volcanic, and Atmospheric Cycles.

We are now in a position to trace the course of events which have taken place all down the ages of the earth's history. The narrative commences with the dawn of life within the ancient ocean. The first link in the apparently never-broken long chain of life and the basis whence more complex organisms have evolved, or have been built up, is the naked protoplasm. It is the substance of all life, and the medium through which the vital impulses are exerted. Life cannot be defined without bodily form. If the form is destroyed the life ceases. We cannot conceive that life takes to itself form. The fact which we take as our starting point is that life and form are one, and that the form which the earliest life on earth assumed was protoplasmic.

Commencement of Earth Building.—The evolution of the earth commenced with the origin of living protoplasm, so that at the outset we are face to face with the great Biological mystery. Great as this mystery is, however, the strongest conviction of the truth of an evolutionary law does not deny, but requires the fact of life, and since all such life has been traced back to a common protoplasmic basis, we are able to see the distant past in the present.

In order to follow the process of earth building, the habits and movements of the minute cells are studied and their means of reproduction discovered. Their delicate structure and physiology are noticed, and after reducing them to powder their chemical properties are analysed. The chemical changes which are wrought out in the building-up of animal and vegetable tissue may be discussed; but, much as is possible in this direction, it is still impossible to unravel the mystery of life's origin, without which these processes cannot be carried on.

This essential and vital force, the outward manifestation of which we call life, is then our starting point in the history of the rocks. We cannot explain life, neither can we explain it away. It is in-

definable, and yet has left mementos of its handiwork throughout the ages of the past. The rocks in which these memorials are preserved show that the earth is the tomb of the organic life of the past. Death is as essential to earth building as life. Both are equally necessary, but equally inexplicable. Birth, growth, maturity, decline, and death are required for the formation of stratified ocean deposits.

Protoplasm and Vital Force.—The protoplasm is the basis of, and enters into the structure of all living organisms. It exists in the individual state, and enclosed within a cell wall of its own construction, or in a naked state without a sheath, and in communities or colonies of cells, all of which are in intercommunication with one another, and form a jelly-like mass. It may be built up into the monarch of the forest or the mammoth of the river or ocean, whose growth is but the reproduction of cellular tissue.

The protoplasm enters largely into the structure of all living organisms, from the simple unicellular protozoa to the more complex human being. It is colourless, slimy, and scarcely distinguishable from water, but under the microscope it is seen to have a distinct structure. The minutest particle of this substance exhibits all those qualities which are associated with life—movement, respiration, reproduction of species, sensibility, and instinct. The protoplasm is the essential part of the cell, and is the basis of life. It is the medium within which and through which the vital energy is able to exert and manifest itself. This vital force is different to any of the other forces of nature, such as electricity, magnetism, gravitation, and cannot be identified with any of them. It only exerts itself through the protoplasm, and is not to be located apart from it. If it ceases its exertion in any part of the protoplasm, that part dies.

Function of Chlorophyll.—One of the principal functions of living organisms is the production of the substances from which tissues are constructed. The process by which this is effected is performed through the co-operation of granules of chlorophyll, which form a part of the constitution of some of the protoplasts. It differs little from the protoplasm, and forms the colouring matter of green vegetation. It is indispensable for the exercise of the productive function. The chlorophyll intercepts some of the rays of light energy which pass through the organism, and converts them into heat and other forms of energy. These are placed at the disposal of the protoplasm, and by their means an organic molecule is constructed from carbon dioxide and water.[1] In this way the simple compounds of hydrogen and carbon, known as hydrocarbons, are produced, and also starch and some oils. Other mineral salts are believed to be necessary to this process, but they do not take any place in the chemical combination.

[1] S. H. Vines, *Student's Text-book of Botany*, 1902, p. 717.

Protoplasm and Environment.—This process is one of first importance. It is the fundamental process in nature by which organic substance is constructed, and three things are essential to it—radiant energy, water containing carbonic acid gas, and the living protoplasm. These conditions are fulfilled in the depths of the ocean, where the *Diatomaceæ* live and die and build up the sea bed. Given, then, the living protoplasm with its required environment, without which it cannot exercise its functions and dies, we have all that is necessary for the commencement of those processes which have been responsible for the building up of the earth's crust.

We are thinking now of the time in the history of the earth when the living protoplasm first appeared within the environment which was suited to the exercise of its function. It lived in the midst of the water or within the Hydrosphere which condensed from the parent nebula. The correspondence which existed between its surroundings and its own constitution was complete. There was a perfect harmony between life and its habitation. Under these circumstances the chemical processes commenced within the protoplasm which changed the gases in the water into compounds, from which it constructed its own protective coat or shell and built up its tissues.

Looking back for a moment to the ancient siliceous rocks of the last chapter which form the opening phase of each sedimentary cycle, it is in the greatest depths of the ocean that the highest percentage of carbonic acid gas is held in solution. The vegetable *Diatomaceæ* and *Radiolaria*, which enter so largely into the composition of siliceous deposits, thus found conditions admirably suited to them in the depth of the Primæval ocean.

Original Minerals not Essential.—If the chemical nature of some of the animalculæ immediately after death is examined, striking facts are brought to light. "It is astonishing to find that *Diatomaceæ* with cell walls sheathed in silica exist in water which contains no trace of silicic acid,[1] and plants usually rich in silica can be brought to an apparently normal development under conditions which render the absorption of silica impossible."[2] If the water lily plant is burnt, the ash is found to be composed of one-third common salt, yet neither the water in which it grew nor the mud into which it plunged its roots contained more than the slightest traces of that mineral. Other plants composed largely of lime grow upon soil where little, if any, calcareous matter is to be discovered. Such phenomena sometimes "quite baffle explanation," but although mystery surrounds the origin of organic matter, the fact remains that living organisms do not depend upon an original supply of

[1] Kerner von Marilaun, *Natural History of Plants*, tr. by F. W. Oliver, 1902, p. 70.

[2] S. H. Vines, *Student's Text-book of Botany*, 1902, p. 716.

silica and carbonate of lime for the construction of shells and tissues, but have the power of raising the potentiality of the simpler elements, and so producing those chemical compounds. In this way the rudimentary components of the original nebula are transmuted by the power of vital force, and a new stellar cycle is commenced whereby a solid terrestrial globe in process of a long evolution is built up. The retrogression or combustion phase of such cycles, which was reversed when condensation ensued and the hydrosphere was formed, is thus changed to an evolutionary and progressive phase. Construction takes the place of dissolution.

Living Organisms as Chemical Agents.—The processes by which these changes are effected are somewhat imperfectly understood, but it is clear that the inorganic kingdom is linked to the organic through the instrumentality of living forms of infinitely simple structure. The organisms with the green colouring matter assimilate as food the simple compounds of carbon and nitrogen. The carbonic acid gas is decomposed and the oxygen liberated, leaving the molecules of carbon free to enter into new chemical combination with other molecules of hydrogen and oxygen to form starch.[1] Food is in this way provided for the animal kingdom which is wholly dependent upon the vegetable world, being unable to subsist upon the simpler chemicals. These and many other reactions take place during the life of the protoplasm, while others again take place during the decay, both of the waste products of life and of the organic tissues after death.

Living organisms have also the power of transforming the soluble lime salts of the ocean, in which they live, into the less soluble carbonate of lime and silica, which are again used for the construction of their protective coats or skeletons. It is supposed that the ammonia salts given off by the decay of tissue are secreted and react upon the sulphate of lime for the formation of the carbonate,[2] which enters so largely into the composition of many rocks. The formation and precipitation of these various insoluble compounds are thus carried out through the intervention of organic life.

Architecture of Earth's Crust.—It is upon these striking facts that reason builds the structure which accounts for rock formation. The sediments of the earliest ages of the earth's history were formed by the precipitation of insoluble compounds by organic means. The architecture of the earth's crust has been primarily accomplished by the many forms of life which have inhabited the oceans in all ages, and upon none more than the microscopic protozoa.

The marvellous reproductive energies and tenacity of life of the very simplest forms of protozoa have rendered them eminently suited to the process of earth building. Their handiwork has been referred

[1] Sir E. Ray Lankester, *Introduction to Zoology*, 1909, vol. xi.

[2] Sir J. Murray, "Coral Reefs and other Carbonate of Lime Formations in Modern Seas." *Nature*, June, 1890, p. 165.

to in some detail in the previous chapter. It has been summarised in a more general way as follows:—"Generations of these tiny creatures lived and died and were entombed in the ever-growing depositions. Succeeding generations pursued their instincts by myriads, happy over the surface which covered the perishing remains of their predecessors, and then died and were entombed in turn, leaving a higher platform and a similar destiny to the generations that succeeded."[1] This process went on as one age succeeded another, and as a new stratum covered up the one that had just been laid down.

Laurentian System Built-up.—It is supposed that the period of geological history represented by the pre-Cambrian rocks is as long, if not longer, than was required for the formation of the Primary, Secondary, and Tertiary systems down to the present day. All through the earlier part of this protracted era the ocean population was busy performing the chemical reactions which produced the variety of sediments, now changed into the granites, which form the Laurentian System or Fundamental Complex. Layer after layer was laid down, until thousands of feet of sediment were produced.

Effects of Accumulation of Strata.—While these microscopic creatures were doing their work in the ocean above, great changes were in progress far beneath. As soon as the deposits had reached a sufficient depth, the enormous pressure set up in the interior produced instability, and the strata were depressed in one area and upraised in another. These movements were, no doubt, gentle at first, but with the ever-increasing depth of sediment, they gradually became more pronounced, and caused greater inequalities in the surface of the ocean bed. The deep-seated layers continued to be bent, folded, and contorted as time went on. They were compressed, extruded, and mashed with the ever-increasing load upon them, while being buried beneath great depths of strata, which were all the while being thrown down upon the ocean bed.

At a later stage in the progress of these earth movements, when the irregularities were very pronounced, the cyclic sedimentary systems commenced to be laid down in the deeper depressions after much detrital material had accumulated. These newer systems were upraised, and depressions were produced in other areas, and fresh deposits were laid down within them.

Metamorphic Phase.—Another phase of this evolution was the result of metamorphism. The temperature of the lower layers commenced to rise with the continued addition of deposit at the surface. The increasing pressure slowly raised the melting point of the rock-forming material, so that it was long before the interior was fused. The rising temperature rendered the sediments highly crystalline through the agency of the included moisture. They

[1] Hugh Miller, *Old Red Sandstone*, p. 244.

were then capable of offering greater resistance to the deforming forces which were being exerted upon them, and, instead of yielding, were crushed beneath the load, only to be welded once more into a homogeneous whole by the metamorphic energy of the heat, moisture, and pressure. These processes repeated themselves again and again until the original character of the mass was lost. The movements which were characteristic of the contortion stage were continued, and contributed to the degree and character of the metamorphosed mass.

Volcanic Phase.—Even another phase of the remarkable progress of events is manifest. At a later epoch the heat energy overcame the pressure resistance, and the deeper strata were locally liquefied. As soon as this was effected remarkable outbursts of volcanic energy took place, dykes of molten matter cut their way across the beds at all angles, and flowed out upon the ocean bed in sheets. It forced its way between and among the strata and liquid veins fused their way in all directions. Volcanoes ejected great quantities of gas, dust, and ash at frequent intervals, which burst through the aqueous envelope, only to fall and settle upon the ocean bed to form new sediments. This activity spent itself, and then another long interval of sedimentation, followed by contortion, crushing and metamorphism ensued. The older dykes and sills, together with the new sediments, were involved. They were crushed and plicated, and are now irregularly distributed among the reconstructed complex. "Through this complicated mass newer groups of dykes have arisen, again to be subjected to similar treatment," when the contortion, crushing, metamorphic and igneous phases have acted in unison.

Plutonic Phase.—The deep-seated sediments are thus subjected to the exceedingly complicated action of a number of natural forces. The accumulation of deposits upon the outside raises the pressure and temperature in the interior. This, in turn, causes the rocks to expand, and further increases the pressure and temperature.[1] At the same time that the pressure rises, another complication intervenes. "It seems to be demonstrated that pressure raises the melting point of average rock, and hence at 20 or 30 miles deep there may be rock hot enough to melt at the surface, but still solid because of high pressure."[2] The pressure may, therefore, become excessive and the heat abnormally high, and yet no liquefaction take place. But since we know that rock has become molten, a time eventually arrives when the heat-energy overcomes the pressure-energy and the lower levels become fused, and the molten rock commences to absorb the upper layers into the magma.

Oceans and Preservation of Crust.—The igneous and volatile matter continues to rise by fusing and fluxing its way upwards. The pressure upon them is reduced, and the temperature of lique-

[1] A. H. Green, *Geology for Students*, 1882, p. 651.
[2] T. C. Chamberlain and R. D. Salisbury, *Geology*, 1905-6, p. 598.

faction slowly falls, which gives the magma access to more and more sediment, and it melts its way still further upwards.[1] Since we know that the whole of the earth's crust has not been involved in this way, how has it been preserved from the molten energy of the interior, which, if this process had continued unchecked, would have involved the whole in total ruin? The answer to this is to be found in the deep oceans above, which readily absorbed the heat as it was driven off in the form of vapour, and ultimately checked the course of the internal fires. When the earth cooled down again, much of this vaporous moisture was precipitated, which further cooled the surface. Cyclic climax and anti-climax follow one another under these conditions, and the crust is preserved and slowly built up.

Fundamental Complex not a Separate Unit.—It is, therefore, probable that there are several distinct systems of rocks, some of which have been metamorphosed and mashed and even melted, in the Basement Complex, so that, if it were possible to take the whole of the Primary, Secondary, and Tertiary systems, with their present complications, interstratified lava beds, and intrusive dykes, and subject them to overwhelming pressure from the outside, compress them together, produce intense heating, contort, pulverise, and mash them almost out of recognition, allow the heated moisture time to operate, and reduce them to the crystalline state, while at the same time leaving isolated remnants of the later rocks exposed to view, an almost identical duplication of the Fundamental Complex would be produced. If the process were carried a degree further, and the interior melted by the high temperature, and allowed to spread upwards in the form of bosses, dykes, and sills, the duplication would be even more complete.

The only means whereby this could be accomplished is beneath another deep sedimentary crust, so that the crystalline basement cannot be treated as a distinct unit. Its development has been the result of long-continued processes which are still in progress. It represents the extreme phase of rock evolution which has continued without interruption from the commencement of geological history, whereby the oozes become schists, gneiss, and granite. Sedimentation is the prime cause of metamorphism, and must, therefore, have long preceded it. Earth formation is a continuous process or evolution. There is no abrupt change from a supposed igneous crust to a sedimentary one, as is required by some hypotheses.

Sedimentary, Volcanic, and Atmospheric Cycles.—Through the instrumentality of a number of cycles of sedimentation and transportation of molten material from the interior to the outside, the earth grew slowly larger and larger beneath the deep, and the crust was built up of organic, fragmentary, and igneous rocks, which,

[1] *Ibid.*, p. 651.

after being highly altered beneath subsequent systems, now compose the Laurentian Complex.

The history of the Primary, Secondary, and Tertiary systems records that the formation of each system was followed by an upheaval of the surface and the condensation of large volumes of moisture upon it before the deposition of the next. Evaporation must necessarily have preceded this condensation, and was no doubt due to the increase in the temperature of the earth's crust on account of the igneous activity.

The sedimentary and volcanic cycles were thus accompanied by atmospheric cycles of evaporation and condensation. The building-up of three-fold systems and consequent upheavals did not yet result in the appearance of the land above the ocean. Although the oceans were more widely distributed as the earth grew in proportions beneath them, and their volume was reduced by igneous evaporation as this chapter of geological history drew to a close, the condensation of the vapours caused an increase in the depth of the sea, and a new cycle of sediment was laid down, beginning with siliceous. By the continued repetition of these cycles, system followed system, until, in process of time, the oceans were shallow enough and the upheavals great enough for the rocks to appear above the sea level.

CHAPTER X.

THE PRE-CAMBRIAN SEAS.

Earliest Sedimentary Terrains confirm Principles—Pre-Cambrian or Huronian Systems—Pre-Cambrian Sedimentation and Earth Deformation—Great Structural Changes—Formation of Conglomerates—Earth Deformation and Ocean Disturbances—Transition Described—Local Details of Transition Rocks—Pre-Cambrian Plane of Erosion—Appearance of Land above the Oceans—Glaciation and Formation of Tillite.

THUS far we have been discussing the principles whereby a rigid and complex earth crust, consisting of igneous and sedimentary material, may be formed by the slow accumulation, metamorphism, and partial liquefaction of organic rock-forming oozes. Oceanic muds are changed by pressure and heat to crystalline schists ; these again are fused and form granite, which by the process of differentiation, while plastic, has assumed a pseudo-stratification. These layers again go through the mill and come out in the form of gneiss. Some of the original oozes may go through all these processes, some only a portion of them, while in other instances the gneiss may be again fused and pass to granite, and this again to gneiss once more. The great variety and equally great volume of igneous rocks with the subordinate quantity of sedimentary rocks in the Basement Complex is thus accounted for, and it is now possible to step from the region of hypothesis to that of actuality.

Earliest Sedimentary Terrains confirm Principles.—Of the sediments, beneath which the initial metamorphism and fusion of the Fundamental Complex was accomplished, only remnants now remain. They are the sedimentary and volcanic series known as the Keewatin in America and Dharwar in India, and consist of from 10,000 to 20,000 feet of quartzites and slates, now gneiss and mica schist and biotite gneiss, which were at the time overlain by a deep limestone formation.

During the period of the deposition of these beds, which was of exceeding long duration, volcanoes were active and contributed to their volume. Towards its close, an epoch of widespread earth-deformation set in. Igneous lavas and traps, together with fragmentary-ejected rocks, were scattered upon the restless waters [1] in vast quantities during the upheaval, and settled upon the ocean bed.

[1] W. H. C. Smith, "The Archean Rocks of Lake Superior." *Bull. Geol. Soc. Am.*, vol. iv., 1893, p. 343.

Underlying rocks were again fused and welled upwards with the invading magma, and more and more strata were absorbed within the volatile mass. Everywhere, over thousands of square miles, sedimentary rocks floated upon the liquid granite, were cut to pieces by it, or absorbed.[1] The magma worked its way upwards with an uneven surface, so that detached areas of strata were folded, and compressed between igneous bosses and ridges. The outer surface at the same time suffered prolonged and profound denudation by exterior forces, and the detrital sandstones so formed were re-assorted and distributed upon the sea floor in the form of conglomerates, which were often mingled with the volcanic products. The period of erosion seems to have continued for a long period after the magma had cooled down, so that the sedimentary cover was denuded to the bed rock formed by it, before the next system commenced to be formed.

Pre-Cambrian or Huronian Systems.—By means which have already been discussed, the seas again transgressed and formed the pelagic depths within which the Huronian and Kadapah cycles were built up by the various sedimentary processes. The Lower and Middle systems were in process of formation for countless ages, during which vulcanism manifested itself from time to time, and varied the character of the strata by trap and ash beds. Ocean currents produced lamination of shales, ripple-marking, and current-bedding in the sands, and local conglomerates. The rocks formed at this period vary from complete organic cycles to massive volcanic beds, while other systems consisted of organic, clastic, and volcanic material in association. The evidence seems to show that igneous outbursts were more frequent as the ages passed. The intervals between each system were marked by considerable disturbance and denudation of the lower one, and as the volcanoes increased in magnitude so the denudation increased in intensity. At the close of the Mid-Huronian epoch, the earth deformation, magmatic fusion, vulcanism, and erosion were repeated on a grand scale. Mountain ridges were thrown up, and vast quantities of lava, trap rock, and ashes were ejected or intruded into the stratified series, which were folded and metamorphosed, while great quantities of older strata were absorbed by the magma. Once more the erosive agencies were in evidence, and many thousands of feet of lower and mid-Huronian sediments were swept away to form the base of the next system. The oceans again transgressed, and the upper-Huronian deposits were laid down upon the metamorphosed platform laid bare by the removal of the previous systems.

The same events were again repeated at the close of the upper-Huronian, so that by the repetition of absorption from below and denudation from above, the older rock systems were more and more

[1] F. D. Adams, "The Bases of pre-Cambrian Correlation," in Bailey Willis and R. D. Salisbury's *Outlines of Geol. History*, 1910, p. 14.

incorporated within the metamorphic and igneous regions, or swept away, and only fragments remained in their original form. For the same reason, each succeeding system is known over wider regions than the last. The Keewatin system or its equivalent is only known in the Lake Region of North America, perhaps in Montana, and in Southern India. The Animikie and lower Vindhyan and Hu-to of America, India, and China respectively, which are probably of about the same age, are widely distributed, or were so in each Continent. The oceans in which the upper Huronian commenced to form extensively transgressed the remnants of the mid-Huronian.

Pre-Cambrian Sedimentation and Earth Deformation.—The upper-Huronian system is the last of the pre-Cambrian in which the orderly process of cyclic sedimentation was carried on, and consists of quartzites, red argillites, and slates, calcareous shales, and limestone. They are 12,000 feet in depth in Montana and 8,000 in North China. After the accumulation of the greater part of the limestone, and towards the close of the extended epoch, one of the most decided and well-marked periods of earth deformation

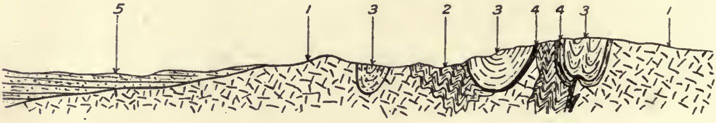


Fig. 10.—Pre-Cambrian Folding in Lake Superior Region.—1, Laurentian Gneiss. 2, Keewatin schists, etc. 3, Huronian, quartzites and slates. 4, Volcanic rocks. 5, Cambrian sandstone later than folding. (C. R. van Hise and C. K. Leith, *U.S. Geol. Survey, Mono.*, vol. lii.)

of the geological record ensued. The granite magma once more fused the old basement and intruded the sedimentary cover, veins, and dykes penetrated it in all directions, vast quantities of lava were outpoured, and dust and ashes showered upon the ocean floor. The sedimentary rocks were thrown into folds or upraised above sea level. Much of the older strata was gripped within the troughs of the uprising bosses and ridges or melted and absorbed by them.

Crustal disturbances produced by this period of volcanic activity warped the more recent sedimentary rocks, some of which were thrown into broad undulating folds. Where the sub-crustal fusion was more active, the rocks were crumpled and inverted, and now lie at all angles and in all directions from the vertical to the horizontal,[1] as if they had floated like wreckage upon a molten ocean. Earthquakes were widespread, and probably affected the whole earth's envelope, and volcanic action was so extensive that wide regions were covered with lava and ash poured out upon the ocean

[1] J. P. Lesley, "Summary Description of Geology of Pennsylvania." *Geol. Survey Pa.*, vol. i., 1892, p. 127.

bed and surface of the land sometimes amounting to 40,000 feet in depth.

Great Structural Changes.—The structural changes brought about at this time in America probably influenced the course of the whole of succeeding geological history. A fault system was brought into existence with a displacement of from 400 to 4,000 feet in the Grand Cañon region, which was uplifted about 12,000 feet.[1] Another similar fracture took place in the Eastern States.[2] The old rocks in America, Scotland, India, and China were folded, elevated, depressed, steeply inclined, weather-beaten, eroded, and sculptured into regions of hills and valleys.[3] There is evidence that as much as 14,000 feet of strata were swept away in some places.[4] The next sediments were laid down upon the denuded or truncated edges of the earlier rocks.[5] The disturbances, faulting and over-thrusting, were the superficial expression of the deep-seated intrusions.[6]

Formation of Conglomerates.—If the evidence of modern earth tremor is to be taken as a guide to past events, the upraised rocks, towering high above the sea at this time, were shattered and cleaved by the earthquakes, and avalanches of debris continually showered down the mountain sides.[7] It was then rolled about and assorted by the restless waves which repeatedly swept across the strand. These tidal waves were the direct consequence of the earth movements, and have their modern counterpart in the "veritable heaving of the bosom of the earth,"[8] which often accompanies such phenomena.

The sand and pebbles put within the reach of the waves by the repeated avalanches and continued ejection of volcanic ash were carried for considerable distances, and were accumulated in hollows beyond the reach of the breakers. By this means vast accumulations of coarse sandstone and pebbly conglomerates and volcanic rocks of all grades were laid down at various parts of the earth's

[1] C. D. Walcott, "Study of a Line of Displacement in the Grand Cañon of the Colorado in N. Arizona." *Bull. Geol. Soc. Am.*, vol. i., 1890, p. 58.

[2] J. P. Lesley, *l.c.*, vol. i., p. 119.

[3] J. P. Lesley, *l.c.*, vol. i., p. 88. Bailey Willis, *Research in China*, vol. i., part 1, 1907, p. 164. R. D. Oldham, *Manual of Geol. of India*, 2nd ed., 1893, p. 99. W. O. Crosby, "Archean-Cambrian Contact near Manitou, Colorado." *Bull. Geol. Soc. Am.*, vol. x., 1899, p. 163.

[4] R. D. Irving and C. R. van Hise, "The Penokee Iron-bearing Series of Michigan and Wisconsin." *Geol. Survey U.S., Tenth Ann. Rep.*, part 1, 1890, p. 454.

[5] W. G. Wilson, "Geol. of Nipigon Basin." *Geol. Survey Canada Mem.*, vol. i., 1910, p. 23. F. R. Mallet, "The Vindhyan Series." *Geol. Survey India, Mem.*, vol. vii., 1871, pp. 57-58.

[6] F. D. Adams, "The Basis of pre-Cambrian Correlation," in Bailey Willis and R. D. Salisbury. *Outlines of Geol. History*, 1910, p. 17.

[7] R. A. Tarr and L. Martin, "Recent Changes of Level in the Yakutat Bay Region, Alaska." *Bull. Geol. Soc. Am.*, vol. xvii., 1906, p. 31.

[8] R. T. Hill, "Pélé and the Evolution of the Windward Archipelago." *Bull. Geol. Soc. Am.*, vol. xvi., 1905, p. 273.

surface. They are now known as the Keeweenawan in the United States, the Athabascan in Canada, the Torridonian sandstones in the North-West of Scotland, the Upper Vindhyan in India, and, locally, as the Camp Creek series in Montana. Similar fragmental rocks of both aqueous and volcanic origin are exposed in Pembrokeshire, Leicestershire, and Shropshire, where they vary in depth from 3,000 to 5,000 feet; they reach a maximum thickness of 16,000 feet in Scotland, and the enormous depth of 60,000 feet in parts of the Lake Superior region, where they are known to have covered an area of 40,000 square miles in the latter region and 24,000 in Canada. There are numerous exposures extending for thousands of square miles in India.

Earth Deformation and Ocean Disturbances.—The accumulation of these conglomerates was, no doubt, due in part to the causes next to be described, but since similar fragmentary rocks were formed under similar circumstances at subsequent periods, it is perhaps advisable to enumerate the reasons for thinking that they were produced by the disintegration of older rocks by tidal waves set up in the sea by seismic disturbances of the ocean bed. At this and many other epochs, the formation of aqueous conglomerates was contemporaneous with granite intrusion,[1] crustal disturbance, and effusion of igneous rocks. The latter phenomena have been associated as cause and effect,[2] and volcanic activity is believed to be directly connected with faulting by competent authorities. It is also sometimes possible to trace changes in the character of one particular stratum, from volcanic flows through coarse conglomerates, volcanic, and semi-volcanic clastics to non-fragmental aqueous sediments,[3] which clearly connects disturbed sedimentation and disturbed seas with the volcanic activity. These conglomerates and clastic rocks are manifestly the result of strong wave action, and we have evidence that such tidal waves are produced by earthquakes and faulting. During an earthquake in Alaska in 1899 the land swayed and waves rose and fell 80 feet every few minutes. Great destruction was wrought up to 40 feet above sea level, producing such a scene of devastation as only rushing water could produce.[4] This was the result of slight shocks, with faulting amounting to a few feet only. The regional disturbance, exceptional faulting, and magmatic invasion of the period under discussion must have effected indescribable commotion in the oceans, and it is often in

[1] C. R. van Hise and C. K. Leith, "The Geol. of the Lake Superior Region." *Geol. Survey U.S., Mono.*, vol. lii., 1911, p. 394.

[2] C. S. Middlemiss, "Revision of the Silurian-Trias Sequence in Kashmir." *Geol. Survey India Record,* vol. xl., part 3, 1910, p. 210.

[3] R. D. Irving and C. R. van Hise, "The Penokee Iron-bearing Series of Michigan and Wisconsin." *Geol. Survey U.S. Tenth Ann. Rep.*, part 1, 1890, p. 441.

[4] R. A. Tarr and L. Martin, "Recent Changes of Level in Alaska." *Bull. Geol. Soc. Am.*, vol. xvii., 1906, p. 49.

the localities where the evidence of disturbance of rocks is strong that the coarse conglomerates are developed.

The early vulcanism was no doubt coincident with earth and ocean disturbances, and at the same time, heating of the crust caused evaporation of the seas. After the vulcanicity had reached the climax and commenced to moderate, the crust still continued to heave and tremble, and was further denuded by the storms which accompanied the condensation as cooling set in. We have evidence, not only of the strong tidal waves, in the current bedding of the sandstones, but also of the storms which beat upon the exposed sands and left impressions in rain-pitted surfaces.

Transition Described.—The events which took place at this period of transition may be thus described. Folding and disturbance of the upper Huronian and earlier strata and eruption of lavas upon the ocean bed, set up unusual commotion in the seas. Tidal waves collected the fragmentary volcanic rocks and other similar material brought down by avalanches, as they swept across those ancient beaches. The fragments of stone were rolled upon themselves and rounded into boulders and pebbles by the sweeping currents. Sand and small pebbles were held in suspension by the agitated water, and made the waves an effective agent of erosion as they pounded the rocky shores. While this was in progress, the oceans were receding on account of the evaporation, so that the cutting edge of the sea had access to land that was being exposed at successive lower levels. The same surface was further cut down by similar means when condensation set in, and the oceans again transgressed. The erosion accomplished by successively retreating tidal waves was supplemented by similar advancing tides and the storms which accompanied them. These heavy rains commenced to fall as soon as the volcanic activity had sufficiently moderated, and the atmosphere was no longer able to sustain the clouds of moisture. The vapours condensed so rapidly that swollen rivers swept over the land towards the ocean. This commenced before the earth had come to rest, so that the seas were still in a state of turmoil, and the rivers encountered the advancing tidal waves. These were rising with the continued condensation, so that each tide transgressed further than the last and the rains, rivers, and waves built up a profound accumulation of conglomerates and sandstones in roughly assorted and false-bedded layers varying in depth from 2,000 to 11,000 feet.[1] Deep valleys were filled up, and mountains 2,000 feet in altitude in Scotland were buried with coarse debris, which bears evidence of having been somewhat rapidly accumulated. The oceans eventually submerged the Highlands of Scotland and America and other parts of the world, and in coming to rest preserved the land from further devastation.

[1] C. D. Walcott, "Correlation Papers—Cambrian." *Geol. Survey U.S. Bull.*, No. 81, 1891, p 365.

Local Details of Transition Rocks.—Local details of the structure of these sandstones appear to enforce the general conclusion. Lava flows are inter-stratified with great boulder conglomerates in the lower Keeweenawan of the Lake Superior region; the middle division records the continued action of the combined igneous and aqueous forces,[1] and is mainly composed of vast beds of conglomerate and agglomerate and other volcanic products; the upper Keeweenawan lies upon a distinct plane of erosion, which is again cut at a considerable angle by another similar plane of denudation produced by the concluding transgression.[2] It is plain that during and after the formation of these transitional rocks earth movements were in progress, and the older and recently formed beds were turned up steeply.[3] The planes of the stratification in the Torridonian sandstones are inclined at a considerable angle to the plane forming the base of the Cambrian system for similar reasons. Rain-pitting, heat-cracking, ripple-marking, and current-bedding are common to these rocks in America,[4] India,[5] and Scotland,[6] where the whole series is characterised by false-bedding and other signs of current action.

Pre-Cambrian Plane of Marine Erosion.—One of the most persistent and striking results of these events is seen in the character of the surface which constitutes the base upon which the overlying system was deposited. The ancient continents were practically base-levelled by and during the encroachment of the Cambrian seas.[7] A plane of erosion cuts right across the Grand Cañon series, and extends [8] for long distances beyond, and has been traced to Texas, Wyoming,[9] Wisconsin, the Mississippi region of the Rocky Mountains, the Lake district of Canada, where the Cambrian sediments are nearly horizontal, and rest on a nearly even surface of the truncated edges of the earlier schists,[10] as well as in Newfoundland.

The basal sediments of the Primary system in China lie upon a

[1] C. R. van Hise and C. K. Leith, "The Geol. of the Lake Superior Region." *Geol. Survey U.S. Mono.*, vol. lii., p. 394.

[2] *Ibid.*, p. 416.
[3] *Ibid.*, p. 235.

[4] *Ibid.*, p. 417.

[5] F. R. Mallet, "The Vindhyan Series." *Geol. Survey India, Mem.*, vol. vii., 1871, p. 95. E. W. Vredenberg, "Geol. of the Strata of Panna." *Geol. Survey India Records*, vol. xxxiii., 1906, p. 271.

[6] B. N. Peach and Associates, "The Geological Structure of the North-West Highlands of Scotland." *Mem. Geol. Survey U.K.*, 1907, pp. 272-3.

[7] C. R. van Hise and C. K. Leith, "Pre-Cambrian Geology of North America." *Geol. Survey U.S. Bull.*, No. 360, 1909, p. 36.

[8] C. D. Walcott, "Pre-Cambrian Fossiliferous Formations." *Bull. Geol. Soc. Am.*, vol. x., 1899, p. 215.

[9] N. H. Darton, "Geol. of the Bighorn Mountains, Wyoming." *Geol. Sur. U.S. Prof. Pap.*, No. 51, 1906, p. 24.

[10] W. G. Wilson, "Geol. of the Nipigon Basin" *Geol. Survey, Canada, Mem.*, vol. i., 1910, p. 117.

relatively flat surface sculptured from the Fundamental Complex.[1] Hard granite and soft schist were reduced approximately to a common base level. The persistence of such a plane of denudation, forming the floor beneath the Cambrian quartzites in the North-West of Scotland, is one of the prominent features of these Highlands [2] (see Plate IV., Fig. 1). Without exaggeration, it may be described at once as the most widespread, strongly accentuated, and deeply significant structural feature of this part of the geological record.[3]

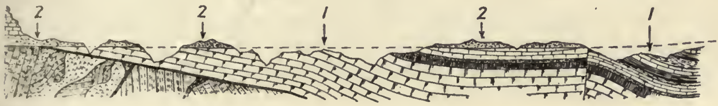


Fig. 11.—Pre-Cambrian Plane of Marine Denudation in the Grand Cañon District of Colorado.—1, Disturbed pre-Cambrian terrains. 2, Cambrian sandstone on plane. (C. D. Walcott.)

The cause of the plain, featureless surface of erosion has been the subject of some discussion. It is believed by some geologists to be due to marine denudation by the breakers of the advancing sea,[4] but there is one circumstance connected with it that apparently points to the contrary. With the exception of an occasional pebble at the base, the first member of the Cambrian is a nearly pure white Quartzite.[5] The old rocks were not only cut down by the gnawing edge of the sea, if it was the work of the ocean, but the newly-formed

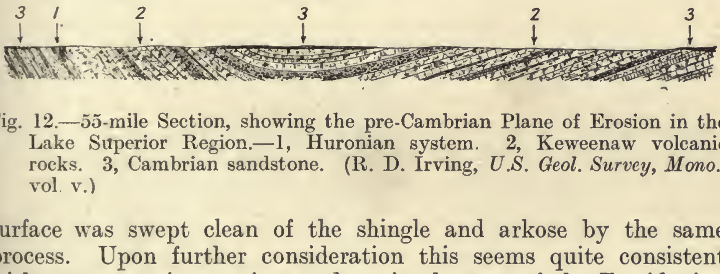


Fig. 12.—55-mile Section, showing the pre-Cambrian Plane of Erosion in the Lake Superior Region.—1, Huronian system. 2, Keweenaw volcanic rocks. 3, Cambrian sandstone. (R. D. Irving, *U.S. Geol. Survey, Mono.*, vol. v.)

surface was swept clean of the shingle and arkose by the same process. Upon further consideration this seems quite consistent with strong marine erosion, and, as in the case of the Torridonian sandstones, the pebbles and sand were swept from the uplands into depressions. The contemporaneous cutting down of the cliffs and filling up of basins contributed to the formation of the remark-

[1] Eliot Blackwelder, *Research in China*, vol. i., part 1, 1907, p. 21.

[2] B. N. Peach and Associates, "The Geol. Structure of the N.W. Highlands of Scotland." *Mem. Geol. Survey U.K.*, 1907, p. 363.

[3] W. O. Crosby, "Archean-Cambrian Contact in Colorado." *Bull. Geol. Soc. Am.*, vol. x., 1899, p. 157.

[4] B. N. Peach and Associates, *l. c.*, p. 363. W. O. Crosby, *l. c.*, p. 161. Bailey Willis, *Research in China*, vol. i., part 1, 1907, p. 165.

[5] Bailey Willis, *l. c.*, vol. ii., p. 32. W. O. Crosby, *l. c.*, p. 163.

able surface plane, so that the production of the peneplane agrees with the accumulation of the eroded material.

Appearance of Land above the Oceans.—This period of geological history is probably noted for the first marked appearance of land above the ocean. There are few, if any, indications of surface conditions in the marine deposits of the earlier systems. There are certain ripple marks and heat cracks in some of the older quartzites which are sometimes taken to be evidence of shore conditions, but as they are in rocks of decided pelagic origin, and may be explained by submarine currents and subterranean heat after deposition respectively, they are not certain evidences of shores. The rain pitting in the transition sandstones is the first indisputable evidence of the appearance of land above the ocean, but, in addition to this, there are other equally strong proofs.

Glaciation and Formation of Tillite.—Whereas previous uplifting of the earth surface had resulted in condensation of moisture, the cooling which followed the pre-Cambrian upheaval was sufficient to produce glaciers upon the higher summits and plateaux, which commenced to grind them down. The glacial boulder beds, or tillite, formed in this way are composed of similar sandstones to those already described, but contain a proportion of stones which bear evidence of glacial scratching and striation (see Plate IV., Figs. 2 and 3). This tillite has, so far, been discovered in five places low down in the Cambrian series in Northern Norway, China, India, Africa, and Australia.[1] The Australian beds contain large and small boulders, some of them 11 feet in diameter. Occasionally they are scratched and furrowed in a way that can only be accounted for by the grinding action of glaciers. The boulders are irregularly distributed in a mass of finer clay and sand, 1,500 feet thick, which covers an area 460 miles long and 250 miles wide.[2] The striated erratics are so arranged that they can only have been deposited where they are by floating icebergs, but must first have travelled for long distances beneath glaciers. Some of the boulders removed from the Highlands in this way were heaped up in the form of moraines. Others remained within the ice flows, which were lifted from their seats by the transgressing sea, and released and deposited upon the ocean floor when the ice melted.

[1] T. C. Chamberlain and R. D. Salisbury, *Geology*, 1905-6, p. 273. Bailey Willis, *Research in China*, vol. i., part 1, 1907, p. 269.

[2] Rev. W. Howchin, "Glacial Beds of Cambrian Age in South Australia." *Quart. Journ. Geol. Soc.*, vol. lxiv., 1908, p. 234.

Fig. 1.—Pre-Cambrian plane of marine denudation in the North-West Highlands of Scotland. Cambrian white quartzite on Torridonian sandstone.

Plane indicated by the arrows.

British Survey Photograph.

Fig. 2.

Fig. 3.

Glaciated Boulders from the Lower Cambrian of China.

Bailey Willis, "Research in China."

CHAPTER XI.

THE PRIMARY EARTH.

Cambro-Ordovician Cycle on Uniform Plain—Vulcanism and Siluro-Devonian Cycle—Increasing Land Areas and Renewed Vulcanism—Oceanic Commotion and Marine Denudation—Old Red Sandstone Disturbances in many Parts of the World—America—Asia—South Africa—Queensland —Great Moine Thrust—Conception Earthquake and Ocean Waves.

Standing upon the threshold of the new epoch in the earth's history and looking back, the scenery had been an almost unbroken expanse of ocean. Looking onwards towards the present, continents soon began to appear and increase in proportions until wider and wider areas were exposed and became clothed with forests. The surface of the islands which composed the landscape at the close of the pre-Cambrian age were rocky, sterile, or glaciated. The land which was about to be formed was rich and fertile in the extreme.

Cambro-Ordovician Cycle on Uniform Plain.—A review of the very widespread plain of marine denudation just described suggests that the earth was moulded by the action of the sea to a comparatively uniform contour, so that when the ocean had transgressed once more, it was practically enveloped in its entirety by an exceptionally deep ocean, with no doubt here and there prominences rising above sea level. This is further indicated by the numerous instances where the quartzites of Cambrian age point to pelagic depths. It was thus a widespread and deep transgression which prepared the way for the deposition of the sediments which now compose the Cambro-Ordovician system. Organic sedimentation continued with little interruption in many parts of the world throughout the whole of this protracted era. In the Mississippian basin, however, the lower Primary rocks are so arranged that the sea bed must have been slowly depressed and gradually elevated alternately during this protracted period, so that pelagic quartz rock and deep sea limestone frequently alternate. While the quartzites, slates, shales, and limestone were being added to the earth's crust (if the evidence of the character of rock is any criterion) the oceans were reduced in depth from about 5,000 fathoms at the dawn of the Cambrian to 500 at the close of the Ordovician in many parts of the earth. Several thousands of feet of rock were somewhat uniformly distributed over the older rocks of pre-Cambrian age.

The enormous depth of these formations is indicated in Plate V., which also impresses one with the great length of time required for their deposition.

It was this period of the earth's history that Prof. Bailey Willis has referred to as " one of the most definite time records of geological history." The trend of evidence in America, Europe, and Asia is to establish proof of the general lowering of sea level of world-wide proportions. The seas were withdrawn from extensive areas and shallows and archipelagos of low, flat islands took their place,[1] so that, not only had the oceans become generally shallower, but had retired completely, and left continental land exposed in many parts of the earth. Thus an exceedingly long period of oceanic sedimentation brought about terrestrial condition by the addition of strata on one hand and shallowing of the seas on the other.

Vulcanism and Siluro-Devonian Cycle.—The Upper Silurian or Ordovician in New Brunswick, Nova Scotia, and Wales are composed

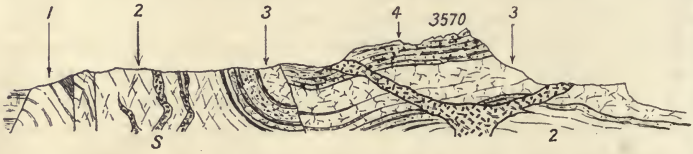


Fig. 13.—Section of Snowdon, 4 miles in length, showing Cambrian and Lower Silurian Quartzites (1), Slates (2), Igneous Rocks (3), and Stratified Conglomerates, Sandstones, and Ash Beds (4). (*Geol. Survey, Eng. and Wales*, Hor. Sec., 28.)

of mixed aqueous and volcanic rocks, or of alternate beds of igneous and calcareous strata. There was a prolonged period of igneous activity, which produced a great series of lava flows in North Wales and Cumberland. Snowdon itself is built of lava and ash poured out or ejected at this time. The sills and beds of trap have been contorted and upheaved to great altitudes, as may be seen in the accompanying diagram. The locality has, however, been subjected to later disturbances, and the rocks do not now lie in the same relations as when originally upheaved. The accumulation of sediment in deeper centres of the depressions thus produced local heating of the underlying rock, and the igneous outbursts, following the line of least resistance, welled up at these points, burst through the strata, and forced their way among the beds, and flooded the surface. These disturbances, taking place where the concentration of the weight of the surrounding rocks was greatest,[2] caused them to creep or slide towards the igneous centre from all directions. The layers were contorted and thrust upwards in the form of a mountainous mass or ridge. Neighbouring beds were less disturbed

[1] Bailey Willis, *Research in China*, vol. ii., 1907, p. 51.
[2] J. N. Le Conte, *Elements of Geology*, 5th ed., 1903, p. 273.

PLATE V. [To face page 100.

GORGE ON THE UPPER YANGTZEKIANG THROUGH CAMBRO-ORDOVICIAN LIMESTONE.

To illustrate the proportions of the ancient formations.

and formed dome-shaped undulations. Subsequent elevation and denudation have exposed the contorted lavas and sediments to view. The progress of these events in North Wales has been worked out in detail upon the ground by Mr. Harker.[1]

Cambro-Ordovician sedimentation thus also produced local internal heating, so that, as the period drew to a close, volcanic action once more commenced to assume grand proportions in the North of England, North Wales and New Brunswick. This again caused slight earth disturbances, local sagging of the ocean floor, and trangression of the seas in which the Siluro-Devonian system was laid down in Pennsylvania, New York, Michigan, Ontario, Hudson Bay, Nova Scotia,[2] and also the Western States—that is, throughout almost the whole of North America. Sedimentation commenced with coarse sandstones and shales, which were the corollary of the earth movements and transgressing seas, which produced submarine wash and disturbance of recently formed muds and clays.

This system is composed of a complete suite of strata in the majority of the States mentioned, which have already been described. Further east in New Brunswick, the deposits, from the Clinton Shales to the Niagara Limestone, are interstratified with trap beds and shales,[3] which point to the continued vulcanicity and unrest in the seas. The alternation of shale and limestone with the grits, mudstones and conglomerates of Wanlock and Ludlow age in Wales, the South of Scotland,[4] and Central China,[5] indicate that these conditions were by no means local. Further away from these centres of disturbance, as in Montana and Tibet, uninterrupted sedimentation continued on into Lower Devonian times. The local volcanic activity was probably the direct result of the addition of the massive Cambrian, Ordovician, and Silurian rocks, and was the prelude to the more general changes which took place in the mid-Devonian age.

Increasing Land Areas and Continued Vulcanism.—The events which marked the close of the Cambro-Ordovician were repeated at the conclusion of the Siluro-Devonian, both of which probably represent periods of geological history equally long. Oceanic sedimentation in each instance was followed by Continental con-

[1] A. Harker, *Bala Volcanic Series of Carnarvonshire*, 1889, p. 219, *et seq.*

[2] A. C. Lane, "Notes on the Geological Section of Michigan." *Am. Journ. Geol.*, vol. xviii., 1910, p. 395. C. S. Prosser, "The Thickness of the Devonian and Silurian Rocks of Central New York." *Bull. Geol. Soc. Am.*, vol. iv., 1893, p. 100. H. P. H. Brummel "On the Geol. of Natural Gas and Petroleum in South-West Ontario." *Bull. Geol. Soc. Am.*, vol. iv., 1893, p. 237. Sir J. W. Dawson, *Acadian Geology*, 4th ed., 1891, pp. 567-9.

[3] Sir J. W. Dawson, *Ibid.*, p. 578.

[4] B. N. Peach and J. Horne, "Silurian Rocks of Scotland." *Mem. Geol. Sur. U.K.*, vol. i., 1899, p. 56.

[5] Bailey Willis, *Research in China*, vol. ii., 1907, pp. 56-7.

ditions, and it is believed that "the upper Silurian was a time of increasing emergence of the land over wide areas."[1] The long-continued filling in of the oceans with sediments throughout the Cambro-Ordovician and Silurian ages effected considerable additions to the continental land. The oceans once again became generally shallower, and the oscillations which accompanied the volcanic action brought up considerable areas of the ocean bed, so that littoral conditions and sub-aerial erosion ensued.[2] These preliminary elevations, although gentle, were of widespread extent in Eastern America and Wales. The greater changes which were destined to take place later in late Devonian times were thus foreshadowed in the Helderberg-Oriskany transition.

The late Silurian, as well as the early Devonian, was a time of intense volcanic activity. Rocks were penetrated by dykes, and numerous beds of lava and ash were interstratified with the aqueous rocks, and crustal movements were associated with the vulcanicity. The upper Silurian rocks of New Brunswick, like those of older age in North Wales, are largely composed of volcanic materials. A number of beds of lava and trap are associated with the sedimentary strata. They have been folded, disturbed, and altered in marked contrast to later ones, which are comparatively unaltered.[3] The volcanic activity continued in the lower Devonian, where bedded basalt, vesicular trap, and ashes were thrown out, and now form beds upwards of 3,000 feet in depth. The ash and trap form a volcanic conglomerate.

In one centre of eruption, a granite mass quietly melted its way through the sediments without disturbing them. The adjacent Devonian and Silurian rocks now dip towards it and become slightly contorted near their junction with it, and it would appear that "these beds had sunk into or towards the cauldron of molten granite."[4]

The largest mass of granite in the British Isles is that of the Mount Leinster range in the South-east of Ireland, which was intruded at about the same time.[5]

Oceanic Commotion and Marine Denudation.—The erosion stage of this sequence of events is well seen in the North of Scotland, where it has been described by Mr. MacNair. The ocean bed was dotted with active volcanic vents, which poured forth streams of lava and covered large areas of the sea floor, as much as 6,000 feet in thickness in some instances. At the same time granitic bosses were protruded through the strata. The lower Old Red Sandstone

[1] J. D. Dana, *Manual of Geology*, 4th ed., 1905, p. 535.

[2] S. Schukert, "Lower Devonian Aspect of the Lower Helderberg and Oriskany Formations." *Bull. Geol. Soc. Am.*, vol. xi., 1900, pp. 250, 261.

[3] Sir J. W. Dawson, *Acadian Geology*, Suppl. to 2nd ed., 1878, p. 72.

[4] *Ibid.*, 4th ed., 1891, p. 500.

[5] F. H. Hatch, *Text-book of Petrology*, 1909, p. 297.

which commenced to form at this time is composed of a coarse conglomerate of schistose and quartz pebbles, well rounded and smooth. The lavas of this age are frequently vesicular and probably subaqueous, so that the intrusion of bosses and outpouring of lava, together with the explosions of steam, set up an increasing commotion in the shallow seas and archipelagos. Mountainous waves hurled themselves over submerged reefs and disintegrated them, only to return as their energy was spent and to repeat the process. This continued for a long period, as each new crater poured forth its contents from the bowels of the earth. The rocky shores were disintegrated, and the fragments rolled, ground, and polished. The finer sand was carried in the tumultous water until the paroxysms subsided, when all settled in the form in which they are now found.

The submerged land which bore the full force of these subaqueous storms was to the North-west, where the conglomerates lie upon the Archæan rocks. The boulder beds there are "such as would be laid down by the action of fiercely breaking waves." In the deeper water to the South-east the included pebbles become smaller and smaller, until they pass into a mixture of sand and gravel. The coarse conglomerate is about 1,000 feet in depth, and passes up vertically into a great depth of finer deposit.

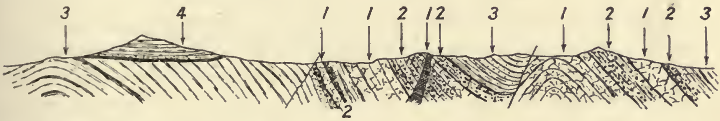


Fig. 14.—Section to illustrate Contemporaneous Igneous Intrusion, Formation of Conglomerates, Folding, and Denudation (4½ miles).—1, Lower Old Red Lavas. 2, Conglomerates and Ash Beds. 3, Sandstone and Marls. 4, Upper Old Red Sandstone. (*Geol. Sur. Gt. Bt.*, Lanarkshire, H.S., 9.)

The lower Old Red of the Southern Uplands of Scotland is of equal interest. In the neighbourhood of old volcanic foci the type of rock varies very greatly. It passes from a confused and irregular mass of angular and subangular fragments of volcanic rock in a fine-grained matrix to a conglomerate, in which the fragments are well rounded; further away the principal constituent is fine volcanic ash, which again is mixed with ordinary sediment, and finally passes into a true red sandstone. The rock fragments were evidently poured out of submarine volcanoes upon the seabed, and were pounded by the waves set up in the ocean by the force of the eruptions. Where lava was poured out, no sooner was one flood cooled than the star-shaped fissures formed by the contraction [1] were filled up with sand held in suspension in the water, before the next stream of fiery liquid covered it up.

[1] Sir A. Geikie, "Ayrshire, Southern District, Exp. Sheet, No. 14." *Mem. Geol. Sur. Scotland*, 1869, p. 13.

The Old Red Sandstones and conglomerates repose upon the folded Silurian rocks in parts of the North of England and the South of Scotland. The upheavals and denudation which accompanied the rock contortion and vulcanism and produced the conglomerates, tended to fill up the greater depressions in the earth's surface: the detrital matter, boulders, and pebbles were swept into the hollows, and now bear the same relationship to the underlying Silurian as the Keeweenawan do to the pre-Cambrian.

Old Red Sandstone Disturbances in many Parts of the World.—These events were not confined to only a few localities, but in many parts of the world they tell the same story. The Devonian stage in America, Asia, South Africa, and Australia was a time of remarkable volcanic activity and rock folding, which was accompanied by the formation of similar massive conglomerates, all of which might be described in the same way. The great depth of these pudding stones required enormously powerful currents for their accumulation, and it may be inferred that in numerous centres the ancient earth crust was in a state of violent tremor, while the oceans above it were in a state of agitation and turmoil which is difficult to describe. It was not only paroxysmal in intensity and magnitude, but continued for a complete geological epoch.

America.—Diagonal lamination and false bedding is a common phenomenon in the Pordage flagstones of Pennsylvania, and irregular ripple marks are abundant in sandy shales. The variety of shells in this formation also testify to rapid infilling with sandy mud flows by broad currents, and the details generally suggest an alternation of deeper and shallower water.[1] Similar conditions continued in the Chemung period. "Oblique lamination characterises the whole of the formation, especially towards the west, where it becomes absolutely universal throughout the whole pile of beds."[2]

Asia.—The lower and mid-Devonian of Northern Siberia consist of shales and conglomerates with volcanic rocks, which sometimes lie upon the upturned older rocks.[3] Similar conglomerates and sandstones from 2,800 to 3,500 feet in depth in Central China are believed to be of the same age.[4]

South Africa.—The most conspicuous feature of the scenery of South Africa is the Table Mountain Sandstone. It occupies large areas in different parts of the Colony, and stands out in bold prominence, owing to its resistance to the denuding agents. It varies from a coarse-grained sandstone, with rounded pebbles of white quartz up to 3 inches in diameter, but rarely more than 1 inch, scattered through it, to a red micaceous shale, and reaches a maximum thickness of 5,000 feet. It often consists of a mass of quartzite,

[1, 2] J. P. Lesley, "Summary Description Geol. of Pa." *2nd. Survey Pa.*, vol. ii., 1892, pp. 1348, 1381.

[3] E. Suess, *The Face of the Earth*, vol. iii., 1904, pp. 82-94.

[4] Bailey Willis, *Research in China*, vol. ii., 1907, p. 62.

usually cross-bedded,[1] which, with the pebbles, reveals the strength of the currents that surged backwards and forwards among the sand now composing it. There are no traces of fossils in these rocks, but they pass up into sandstones and shales with a marine fauna of Devonian age,[2] which indicate the return of quieter conditions.

The Witwatersrand conglomerates, grits, and quartz rocks are very similar to the Table Mountain sandstone, and are followed by a series of volcanic agglomerate and other igneous rocks. These are overlain by the Black Reef beds, which are very variable, from a basal conglomerate to a false-bedded fragmental quartzite, 1,800 to 3,000 feet in thickness.[3] Above this is a massive Dolomite Limestone with Chert, some 7,500 feet in depth, of the same horizon as the Mountain Limestone of Great Britain. The two periods of conglomerate and quartzite formation above and below the volcanic outbursts apparently represent the epoch of aqueo-igneous commotion of Old Red Sandstone times.

Queensland.—The Lower Devonian of Queensland covers an extensive tract of country, and, with the mid-Devonian, measures

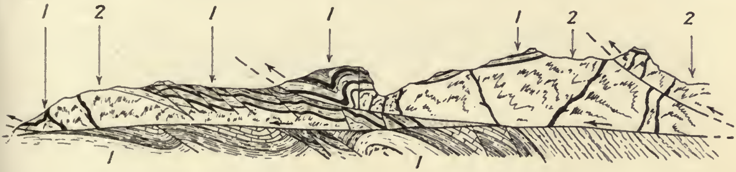


Fig. 15.—Section, 6 miles across Ben More, illustrating the Effects of Successive Thrusts.—1, Cambian Rocks. 2, Lewisian Gneiss. Thrust Planes, —— —— ——. (*Mem. Geol. Sur. Gt. Br.*, North-West Highlands.)

some 20,000 feet in thickness. The original depth was so great that it must represent a greater period than the Devonian alone. The lowest portion is composed of a coarse conglomerate resting upon broad folds of the older rocks, and contains pebbles and granules derived from them, together with dark buff and reddish-coloured shales and ferruginous, chocolate-coloured sandstone.[4] As in South Africa, they are overlain by some 7,000 feet of limestone, which often contains bands of shale and other impurities. The limestones represent an enormous lapse of time subsequent to the period of earth movement, during which organic sediments were built up under comparatively quiet and undisturbed conditions following these disturbances.

Great Moine Thrust.—The position of the igneous disturbances,

[1] A. W. Rogers, *Geol. of Cape Colony*, 1905, p. 113.
[2] F. H. Hatch and G. S. Corstorphine, *Geol. of S. Africa*, 2nd ed., 1909, p. 81.
[3] Do., *Loc. cit.*, p. 173.
[4] R. L. Jack and R. Etheridge, *The Geol. and Palæontology of Queensland and New Guinea*, 1892, p. 40.

the direction of the lines of wave motion, the distribution of the conglomerates, combined with the intensity of the volcanic forces which were exerted at the Devonian epoch in the British Isles, seem to indicate that the great system of thrusts and rock shearing of the North-West Highlands was produced during this period.[1] "The forces exerted in the abysses of the Devonian ocean to the South and South-east, acted as it were at the end of a long lever, whose fulcrum was in the Island of Lewis far to the North-west. The intermediate Cambrian, Torridonian, and older rocks, long since metamorphosed, were heaved upwards, fissured, and thrust over one another towards the fulcrum in remarkable confusion. The north-west and south-east direction of the leverage produced a more or less south-west and north-east line of overfolding, which is the direction taken by the Great Moine Thrust. "Under the influence of the horizontal compression and earth creep, the rocks behaved like brittle rigid bodies, and were folded over each other, snapped across, piled up, and driven westward in successive slices." [2]

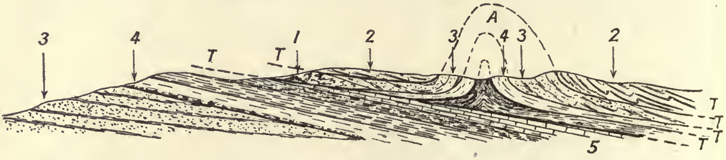


Fig. 16.—Anticline formed by the last of a Succession of Thrusts of Older Rocks over Cambrian Strata.—1, Lewisian Gneiss. 2, Schists. 3, Torridonian Sandstone. 4, Cambrian Quartzite. 5, Cambrian Dolomite. T, T, T, T, Thrust Planes. A, Anticline since denuded. (*Mem. Geol. Sur. Gt. Br.*, N.W. Highlands.)

Conception Earthquake and Ocean Waves.—The effects of the Conception earthquake shock of 1835 give some indication of the forces which were set up by the earth movements and vulcanism of Devonian times. Half an hour after the principal shock, the sea retired from the bay, so that sandbanks, usually from 40 to 50 feet beneath the surface of the sea, were exposed. Then a monstrous wave returned 30 feet above high-water mark and swept all before it. It was followed by a second and a third, each exceeding the previous one in power and more tempestuous than the last, earth and water trembled irregularly and frequently for three days before finally settling down.

This quivering of the earth on the Chilian coast bears no comparison to the vast and continuous earth movements of Lower Old Red times, yet its effects were felt 6,000 miles away, and caused violent floods upon islands in the mid-Pacific. The whole of the ocean oscillated in its bed.

[1] J. A. Jukes Browne, *Building of the British Islands*, 3rd ed., 1911, p. 126.
[2] B. N. Peach and Associates, "The Geol. Structure of the North-West Highlands of Scotland." *Mem. Geol. Sur. U.K.*, 1907, p. 7.

CHAPTER XII.

THE CARBONIFEROUS EPOCH.

Differences in Character of Sedimentation—Cause of Variation in Sequence of Strata—Transgression and Fresh-water Lakes—Denudation again produces Local Conglomerates and Current Bedding—Double Unconformity in Old Red Sandstone—Trangression and Organic Sedimentation —First Terrestrial Vegetation—Character of Land in the Coal Period —Vegetation of the Coal Period—Impressions in Coal Workings described—Climate Variable during whole Epoch—Uniformity of Climate during Growth of Vegetation—Humidity requires Change of Temperature—Light less intense than now—General Character of Climate.

The scenery of the period just described consisted, on the one hand, of widespread continents, which were destined soon to be clothed with luxuriant vegetation and extensive shallow seas, which were in a state of continued turmoil near the centres of volcanic activity. During the transition to the Carboniferous epoch considerable physical changes took place, and the more uniform features of the last period gave place to a great diversity in the new.

Differences in Character of Sedimentation.—The earth disturbances of the mid-Devonian may be compared with those which immediately preceded the Cambrian, but there is a distinct difference between the effects produced in the stratigraphical record. The latter, as we have seen, introduced a regime of pelagic sedimentation in many countries. The rocks of lower Carboniferous age consist, on the one hand, of pelagic quartzites, and, on the other, of massive littoral sandstones. The ocean bed consequently was vastly deepened in some parts, and the land further exposed in others. The former is clearly instanced in the Wasatch and Uinta Mountains of Utah, and also in Belgium and Germany and Northern India, where deep series of quartzites, argillites, and limestones, from 7,000 to 10,000 feet in depth, commenced to be formed with little or no fragmental rocks to mark the transition, while in Pennsylvania, New York, and neighbouring States an enormous depth of conglomerates and irregularly bedded sediments were accumulated; and it is probable that land or littoral conditions existed on to the close of the Primary ages. These two types of sedimentation are typical of the Rocky Mountains of the Western States and of the Appalachian or Eastern States, and the distinction has probably some relation to the great fault system which was produced by the pre-Cambrian deformation.

A large part of the Asiatic continent may be similarly divided.

The northern parts of China, Tibet, and Mongolia were shallow, so that sandstones, shale, and coal beds were formed at the same time that limestones were being laid down in deep water in South China, Burmah, the Himalayas, and Turkestan.[1]

Between these two extremes of wholly fluviatile and wholly organic sedimentation there was a more general type, as in England, commencing with a period of erosion and the formation of conglomerates, passing up into pelagic marls and clays to the Carboniferous Limestone, and followed by the Millstone Grits and Coal Measures. Again, in the extreme East of North America another variation in the order of sedimentation is apparent. Thick beds of conglomerate and soft sandstone lie upon the disturbed older rocks, and are followed by the Lower Coal Measures forming together the base of the Carboniferous. This series consists of marine limestone, the Millstone Grit, and Coal Measures proper.[2] There is, therefore, a considerable variety in the arrangement of these rocks in various parts of the world.

Cause of Variation in Sequence of Strata.—These differences were evidently the result of crustal readjustments after the Devonian volcanic episode. The consequent earth movements were long in finally coming to rest, and were accompanied by aqueous precipitation and erosion of the exposed land in some instances, and deepening of the oceans in others. The evidence thus suggests that differential movements of elevation and depression were responsible for the various arrangements of the strata just referred to, so that uniformly shallow water and low land elevations were characteristic of the Devonian, pelagic oceans on the one hand, and continents on the other were established in the early Carboniferous.

The widespread lowering of the oceans and introduction of general shallow and littoral conditions in the mid-Devonian was thus followed by an almost equally world-wide transgression, which has been traced through Europe, North America, and Asia.[3] "And it was at the period represented by the lower portion of the Upper Devonian that the greatest extension of the sea took place at this time."[4] That is to say, that a world-wide epoch of sedimentation, with the consequent manifestation of vulcanism, was succeeded by a universal lowering of sea level. After the volcanic episode had closed as it did, the seas again transgressed in those areas where pelagic sediments were laid down, but left the higher land above sea level.

Transgression and Fresh-water Lakes.—The transgression was partly due to the readjustment and redistribution of land and

[1] Bailey Willis, *Research in China*, vol. ii., 1907, p. 73.

[2] Sir J. W. Dawson, *Acadian Geology*, 4th ed., 1891, pp. 129, 130.

[3] Eduard Suess, *The Face of the Earth*, tr. by H. B. A. Sollas, vol. ii., 1904, p. 233.

[4] F. Cowper Reed, "Pre-Carboniferous Life Provinces." *Geol. Sur. India, Record*, vol. xl., p. 30.

water, and also to the abundant precipitation of moisture following the cessation of vulcanism. The denudation and return of the seas in this way effected an important change in the fauna in particular localities. It is generally believed that the Upper Old Red Sandstone was laid down in fresh-water lakes. The rocks of this period have been divided into two sections, since the marine Devonian is followed by the fresh-water Old Red Sandstone.[1] The change was evidently effected by the abundant precipitation of atmospheric moisture. It is the first evidence of fresh-water lakes having existed upon the earth's surface.

It is consequently probable that the vast tracts of land exposed to denudation at this time formed extensive lagoons, in which the products of condensation collected and fostered the growth of estuarian and brackish water fauna, and that in the deeper seas marine organic life still flourished. The local transition from marine to fresh-water came about in the same localities where volcanic forces had been rife on both sides of the Atlantic,[2] which seems to demonstrate the direct connection between vulcanicity and the evaporation of the oceans, and the subsequent condensation of the vapours as soon as the crust cools down again.

Denudation again produces Local Conglomerates and Current Bedding.—The currents due to the precipitation of Upper Old Red times eroded and re-arranged the older conglomerates, and prepared the way for the formation of fresh-water sediments. The denudation accomplished by them accounts for the discordance between the lower and upper divisions of the Devonian formation which is apparent in South Wales, Ireland, and the South of Scotland. The distinction between the two horizons is also evident in their structure.

The lower conglomerates of Scotland contain fragments of the older rocks upon which they lie. Those formed after the volcanic phase contain pebbles of eruptive rocks. The conglomerate in South Wales below the discordance is quite distinct from the pebble beds above it. Lower marls and sandstone of East Lothian are followed by the Great Conglomerate, and this again is surmounted by shales of upper Old Red age at the base of the Carboniferous Limestone.

The Pocono formation in Pennsylvania is a conglomerate with large pebbles in the lower horizons, and consists of coarse sandstone in which oblique lamination and current bedding are a remarkable feature. It is sometimes 3,000 feet in depth, and false bedded from top to bottom. There are a few beds representing collections of leaves and twigs which floated into small lakes or ponds, and it

[1] A. J. G. Cole, *Aids in Practical Geology*, p. 108.

[2] Sir J. W. Dawson, *Acadian Geology*, 4th ed., 1891, p. 560. H. S. Williams, "Silurian-Devonian Boundary in North America." *Bull. Geol. Soc. Am.*, vol. xi., 1900, p. 339. J. P. Lesley, "Summary Description of the Geol. of Pennsylvania." *Geol. Survey Pa.*, vol ii., 1892, p. 1432.

also furnishes more salt brine over wider territory than any other sandstone formation in the Primary column.[1] Strong silt and pebble-laden currents carrying floating fragments of vegetation thus scoured the land surface. This was deposited with the sand and silt in which they are now entombed, as the currents slackened in more stagnant pools where the brine had collected during the preceding epoch of evaporation and withdrawal of the seas.

Double Unconformity in Old Red Sandstone.—The earth disturbances and marine denudation described in the last chapter, and the subsequent torrential erosion produced a double unconformity or discordance within the Old Red Sandstone group, which is illustrated in the accompanying sketch. The lower conglomerates lie upon the vertical edges of the Silurian rocks, and the upper upon the denuded surface of the lower.

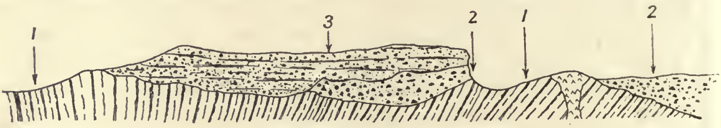


Fig. 17.—Old Red Sandstone in Berwickshire.—1, Lower Silurian. 2, Lower Old Red Conglomerates. 3, Upper Old Red Sandstone. (Sir A Geikie, *Mem. Geol. Sur. Gt. Br.*, vol. xxxiv., Berwick.)

Transgression and Organic Sedimentation.—All the while that this extensive erosion was in progress upon the uplifted and exposed regions of the earth, organic life was once more free to continue the process of earth building in the deeper basins. The first sediments to be laid down were the quartzite or red marls and clays which now form the base of the Carboniferous Limestone. This is a massive rock often of great depth, and represents an extended period of geological history. The colour varies from white and pink to grey, black, and mottled, and as it is generally recognised as an organic formation, it does not require detailed description. Volcanic phenomena are of rare occurrence. The contemporaneous lava flows in these rocks at the mouth of the Severn, and the volcanic bomb of the same age in Fife show that it was not absent in the British Isles, while in Western N. America it extended from Alaska to California. The activity of the igneous interior is shown rather by the slow, but continued, undulations of the ocean bed than superficial volcanic displays. They continued until the close of the Primary epoch, and had an important bearing upon the formation of the Coal measures which succeed the Carboniferous Limestone.

First Terrestrial Vegetation.—The marine geological record of this period is distinct from the terrestrial, so that we shall return to the Upper Silurian rocks in order to follow the progress of events

[1] J. P. Lesley, "Summary Description Geol. of Pa." *Ind. Survey Pa.*, vol. iii., 1895, pp. 1629-1631.

upon land. From that time onwards to the close of the Primary epoch, more and more land became visible above the ocean, so that this was one of the most notable periods of the earth's history. In contrast with the barren and sterile rocks which were upheaved at the close of the pre-Cambrian era, these land surfaces were more like the present continents, and were fertile in the extreme.

It is in the rocks of this period that the first evidence of land vegetation appears. "The earliest known representatives of land plants are found in the Silurian rocks." The older Cambrian flora is limited to the remains of fucoids or floating sea weeds. They are more rapidly decomposed than land plants, so that as they precede the less perishable flora in the geological record, it is probable that the upper Silurian vegetation represents the dawn of fertile continental conditions upon our planet.

In Europe, and also in America, when the Upper Silurian period drew to a close, new lands were thrown up, and still more wonderful change, those lands were clothed with rich vegetation, and the oldest known land animals, delicate and beautiful insects—water-born but true air dwellers—flitted through its glades.[1] The oldest terrestrial vegetation of which geologists have anything like a definite knowledge is in the Lower Old Red sandstone, and even there it is very fragmentary. "The Devonian period probably covers the early development, if not the actual beginning of the terrestrial plant life of the earth." [2]

The early land of the pre-Cambrian epoch was materially added to at the close of the Cambro-Silurian, and this again was further increased in Lower Devonian times. Each transgression appears to have left more and more land exposed above sea level. It was the land thrown up by the lower Devonian volcanic episode that nourished this early vegetation. The more limited forests of this period were entombed by the erosion accompanying the long series of earth movements which preceded and accompanied the Carboniferous transgression, and they now form seams of coal beneath the Carboniferous limestone, as in New Brunswick, or were scattered through the fragmental sands and shales formed at that time. From this time onwards until the close of the Primary epoch an ever-increasing area of continental land was clothed with vegetation in process of time to be entombed in the Coal Measure strata.

Character of Land in the Coal Period.—It is thought that islands were very numerous at this period, and that the emerging land surface formed a vast archipelago, the islands being connected together and formed into continents as they were raised above the ocean. It was in the rich, loamy soil of these newly formed plains that the luxurious forest vegetation of the period thrived. It is

[1] Sir J. W. Dawson, *Acadian Geology*, 4th ed., p. 665.

[2] David White, "The Upper Paleozoic Floras: their Succession and Range." *Am. Journ. Geol.*, vol. xvii., 1909, p. 321.

maintained that true coal is a sub-aerial accumulation of vegetable growth in soils wet and swampy, it is true, but not submerged.[1] Most of the coal, says another writer, resulted from littoral growth, in maritime swamps and lagoons, of various trees and vegetables suited to those conditions.

The coal-formation swamps, lagoons, and creeks must have been for the most part shallow, land-locked, and filled with putrid vegetable matter, though no doubt often at the sea level, and communicating with it by channels more or less wide.[2] "Plant life spread across broad, base level plains and over marshes and lagoons that flanked its long inland-reaching estuaries."[3] "Continuous marshes, peat bogs, and jungles of weeds and ferns occupied immense stretches of the surface of the earth."[4]

Vegetation of the Coal Period.—The forests of the coal period contained trees and vegetation of quite a different character to those which now predominate. The Phanerogamous, or flower- and seed-bearing species, were not represented in any of the higher orders; only the lowest, the Pines and Cycads. These held quite an unimportant place, and were distinct from more recent species. The cryptogamous, or spore-bearing and flowerless plants, were the characteristic flora of the Coal Measures proper. They are the tree ferns, club mosses, lichens, fungi, and sea weeds. The swamps in which they grew, peculiarly suited their means of fertilisation, which was carried on under water. In this respect they differ from the more recent phanerogams which fertilise in the air.

"The most important of the trees of the coal swamps" was the *Sigillaria*, with its rootlets of *Stigmaria*. The trunk consisted of a hard outer rind or bark, often from 4 to 5 feet in diameter, with a thick inner bark of soft, corky, cellular tissue. At the centre was a small cylindrical core of harder wood. The trunk was divided some distance from the ground, but there were no branches like those of recent trees. Long taper leaves or spines grew direct from the trunk and limbs. Although the wood of such trees would be of little use for commercial purposes, it was admirably suited for the production of coal. The scaly bark has resisted decomposition so well that in some instances it forms nearly the whole of thick seams.

Calamites, or giant horse-tails, which belong to another branch of the cryptogamous family, grew in dense brakes on the sandy and muddy flats "near or in the shallow water. They appear to have been the first to take possession of the emerging banks of sand and mud." Ferns were numerous, as were tree ferns, similar to those now found in the Tropics. The *Lepidodendron*, or giant club-moss

[1, 2] Sir J. Dawson, *Acadian Geology*, 4th ed., 1891, pp. 139, 202.

[3] David White, "The Paleozoic Floras: their Succession and Range," in Bailey Willis and R. D. Salisbury's *Outlines Geol. Hist.*, 1910, p. 146.

[4] J. P. Lesley, *Summ. Description Geol. Pa.*, vol. iii., part 1, 1895, p. 1631.

group, were similar in appearance and growth to the *Sigillaria*. There were a number of species of this plant, which was a prominent feature of the landscape.

This strange vegetation grew rapidly in forest jungles, upon the extensive low-lying marshy plains, and in shallow lagoons or in deeper water. While *Calamites* appear to have enjoyed the firmer and more consolidated surface, the *Sigillaria* was adapted to the marshes. It was supported by spirally spreading subterranean organs, from which slender roots were sent out to absorb water from the swampy soil. The *Lepidodendron* seems to have grown in deeper water or in more marshy localities still. Its branches were spread out radially in the swampy soil, or possibly in the water. The vegetation of the coal epoch grew closely together, and formed impenetrable thicknesses of stems, branches, and leaves. Ferns, fungi, and other aquatic and semi-aquatic vegetation grew in profusion at the feet of the larger trees, whose trunks were from 1 to 3 feet in diameter, and from 40 to 100 feet, or even more, in height. The growth was probably so dense that in time the trunks, rootlets, and branches formed a semi-solid mass, which bound itself together, and was afterwards entombed in the stratified rocks in the form of coal.

Impressions in Coal Workings described.—The impressions left upon the roofs of the mines after the removal of the seams of coal have been thus described. "The most elaborate imitation of living foliage on the painted ceilings of Italian palaces bears no comparison with the beauteous profusion of extinct vegetable forms, with which the galleries of these instructive coal mines are overlaid. The roof is covered, as it were, with a canopy of gorgeous tapestry, enriched with festoons of the most graceful foliage, flung in wild irregular profusion over every portion of its surface. The effect is heightened by the contrast of the coal-black colour of the vegetables with the light ground-work of the rock to which they are attached.

"The spectator feels transported as if by enchantment into the forests of another world; he beholds trees of form and character now unknown upon the surface of the earth presented to his senses almost in the beauty and vigour of the primeval life; their scaly stems and bending branches, with their delicate apparatus of foliage all spread forth before him, little impaired by the lapse of countless ages, and being faithful records of the extinct systems of vegetation which begun and terminated in times of which these relics are the infallible historians."

Climate Variable during whole Epoch.—The Coal Measure sequence, which frequently amounts to many thousands of feet of strata, may be divided into a number of separate and distinct epochs, which will be described in the next chapter. The coal lies in beds or seams, which are interstratified with other sedimentary rocks of variable nature, each of which denotes some change of

physical conditions, and one epoch is thus marked off from the next. Periods of long-continued tranquil forest growth alternated with periods during which the vegetation, which had so recently flourished, was destroyed and entombed by means of strong currents of water, beneath sand and silt.

If two of the coal periods proper are compared with one another, there does not seem to be any great distinction worthy of notice between them, but the transition from one to the next was well marked, and the epochal alternations were very variable, and sometimes of long and at others of short frequency. Each change of physical conditions appears to have reacted upon the climate, which was, therefore, very variable throughout the Coal epoch taken as a whole.

Uniformity of Climate during Growth of Vegetation.—The interesting question raised by these changes will receive separate discussion, but during each period of forest growth the climate was remarkable in several respects, and this will now be pointed out. These particulars only apply, however, to distinct phases of a protracted sequence of events, during which the coal flora flourished for long periods without interruption from physical causes.

The period now under discussion extended from the Devonian to the close of the Carboniferous, and the earlier times do not appear to have been marked by changes so decided as the later, for the woods present no rings of growth to bear evidence of seasonal change of temperature or prolonged drought.[1] During subsequent periods, also, when forests flourished far and wide on the globe, the climate was singularly uniform in temperature from one year's end to the other. If we could imagine the year to consist of one long season, with the temperature a little above the present yearly average, such a condition of climate would approximate to what is required by the flora of the Coal measures. "From the evidence of geology, we may reasonably infer that were the difference between our Summer and Winter temperature nearly annihilated, and we were to enjoy an equable climate, equal to or a little above the present mean annual temperature of our islands, we should then have a climate similar to what prevailed during the Carboniferous epoch."[2] A more recent estimate is that it was somewhat higher and not inferior to the summer in those times.[3]

As well as being uniform throughout the year, "the climate of the globe in those days could not have been differentiated into such distinct zones as is now the case."[4] "Similar species of plants

[1] David White, "The Paleozoic Floras: their Succession and Range," in Bailey Willis and R. D. Salisbury's *Outlines of Geol. History*, 1910, p. 143.

[2] James Croll, *Climate and Time*, 1885, p. 442.

[3] P. Bertrand, "Les phénomènes glaciaires de l'époque permo-carbonifère." *Soc. Geol. du Nord. Annales*, vol. xxxviii., 1909, p. 122.

[4] James Geikie, *Structural and Field Geol.*, 2nd ed., 1908, p. 98.

to those of our Coal measures are found within 20° of the Pole, where the land is covered in great part by perpetual ice and snow." The temperature of the whole globe seems to have been nearly the same, from the Equatorial regions up to the Melville Islands in the Arctic Ocean, the same species, now extinct, are met with of equal development at the Equator and at the Pole, and we cannot but admit that, at this epoch, the temperature of the globe was nearly alike everywhere.[1] This is not an out-of-date speculation, but is confirmed by recent writers. Taken collectively, all the criteria upon which these deductions are based "admit of only one conclusion." The most forceful argument of all "lies in the extraordinary geographical distribution of the floras in relative unity over the face of the earth." Humidity must naturally have attended such equability, extending without distinct terrestrial zones, probably completely into Polar regions.[2]

Humidity requires Change of Temperature.—Many eminent authorities have contended that the atmospheric temperature, although uniform, was more tropical than the mean annual range in what is now the Temperate zone. This is inferred from the character of plant life which was comparable with species which are now more generally confined to tropical rather than more northern latitudes. Growth is thus supposed to have been rapid under moist and humid conditions. "With the atmosphere so genial and the oceans so warm, evaporation would be excessive, rains abundant, and mists almost perpetual." [3]

This is perhaps the more generally accepted view of the character of the climate during periods of forest growth. There are considerations, at the same time, which suggest that the temperature was not excessive. Modern plants more nearly related to the Carboniferous flora do flourish best in tropical and sub-tropical latitudes, but are not unknown in more temperate regions. It has also been noticed that cooler latitudes are more suited to the formation and preservation of beds of peat composed of vegetable remains. Decay is more rapid under tropical conditions, and checks accumulation.

It does not, moreover, follow that if the climate was tropical that mists were unusually prevalent, as has been suggested. Heat may be accompanied by aeridity and consequent absence of cloud, and so may excessive atmospheric refrigeration. It appears that the change from one state to the other is conducive to the formation of mists, so that a humid climate marked by moderate but slightly changeful temperature would frequently be misty. If, therefore, the climate of the coal periods was characterised by the prevalence

[1] Sir J. Prestwich, *Geol. Chemical, Physical, and Stratigraphical*, 1886-8, p. 129.

[2] David White, "The Upper Paleozoic Floras: their Succession and Range." *Am. Journ. Geol.*, vol. xvii., 1909, p. 336. E. A. Newall Arber, *Fossil Plants of the Glossopteris Flora*, p. 20, 1905.

[3] J. D. Dana, *Manual of Geology*, 4th ed., 1895, p. 711.

of heavy clouds and thick vapour, it was probably changeful. At the same time, the uniformity is so well established that it was probably uniformly changeable. The actual temperature or average temperature is not so important as the uniformity which was common to the whole globe. Uniformity and humidity are consistent with a moderately high or moderately low temperature.

Light less Intense than now.—Other peculiarities appear to arise from what is known of the vegetation of this period. The ferns and Lycopods which were so abundant usually avoid bright glare. "The nutrition is most rapid, and consequently growth also greatest and most rapid where the light is not too strong."[1] The vegetation was also flowerless. "Plants with flowers and fruit, as those terms are commonly understood, existed not in the true coal period."[2] "There were no flowers, no fruit, no fragrance."[3] There must have been an abundance of light for vegetation to thrive with such prolific vigour as is evident, but in all probability it never or rarely reached the brilliance of an English summer. A moderate light may possibly account for the absence of Phanerogams.[4]

General Character of Climate.—A review of the facts appears to point to the conclusion that the climate was much more uniform than now, probably entirely so throughout the globe, that it was changeable, but whether those changes were due to the same causes as at present will be deferred to a subsequent chapter. The light was sufficiently strong for the vegetation to thrive freely with an abundant supply of moisture from the swampy marshes, and an absence of frost which probably atoned for the moderate degree of illumination. In many respects, therefore, the climate was vastly different to what is now experienced upon our planet.

[1] David White, "The Upper Paleozoic Floras." *Am. Journ. Geol.*, vol. xvii., 1909, p. 338.

[2] E. Hull, *The Coal Fields of Gt. Bt.*, 5th ed., 1905, p. 29.

[3] J. D. Dana, *Manual of Geology*, 4th ed., 1895, p. 667.

[4] A. C. Seward, *Fossil Plants as Tests of Climate*, 1892, p. 104.

CHAPTER XIII.

THE COAL MEASURES.

Mountain Limestone to Coal Measures—Millstone Grits—The Loire Basin—The Belgian Coal Field—The Appalachian Coal Field—South Africa—Australia—Subaerial not Marine Denudation—Volcanic Activity and Subaerial Denudation — Mechanical Sedimentary Cycles — Changing Physical Conditions — Vegetation rapidly Entombed — Fresh - water Fauna in Coal Measures—Methods of Accumulation of Coal—Duration of Coal Period—General Effects of Repeated Cycles.

We now take up the narrative again at the close of the Mountain Limestone period, after some thousands of feet of organic rock had been built up beneath the oceans by corals, crinoids, foraminifera, and mollusca. These denisons of the deep pursued their occupation in the wide stretching seas, while the vegetation described in the last chapter grew upon neighbouring shores and low-lying lands. During the period now to be described, the forests of successive generations, which spread far and wide throughout long intervals of repose, were entombed in beds of sand and silt, and preserved for the needs of subsequent civilisation.

Mountain Limestone to Coal Measures.—The passage from the massive deep sea limestone of the Carboniferous series to the next formation is not a gradual one, but marks a somewhat sudden change of physical conditions. There is the greatest possible contrast between the massive and uniform organic limestone and the irregular stratification and fragmentary composition of the Millstone Grits. For long eras the organic protozoa had been accumulating oozes upon the sea floor, but their work now ceased, in certain localities, and atmospheric agencies played the predominating part in the constructive process. Parts of the lithosphere which had hitherto been submerged were slowly upraised and formed shallow basins, which received sand and silt derived from the land. The closing chapter of Primary history recounts the continuous alternation of periods of widespread aqueous erosion, during which pebble beds were rapidly accumulated, with long periods of quiet and undisturbed organic sedimentation and forest growth.

This period is even more marked than previous ones by the appearance of extensive tracts of fertile land above the ocean level. This is believed to be due in part to the gradual shallowing of the ocean, so that sand and silt-laden currents could spread themselves

out for great distances,[1] as well as to elevation of the sea bed, of which there is some evidence. Throughout a protracted epoch, littoral erosion was performed on account of repeated oscillations of the land at long intervals. These events were in operation throughout the whole of the Carboniferous epoch in the Appalachian region of the United States of America, where similar changing physical conditions prevailed from Upper Old Red Sandstone times to the close of the Primary epoch, so that the following particulars generally apply to a very much longer period there than in England.

Millstone Grits.—The result of this change of conditions is clearly written upon the basal conglomerates, sandstones, and shales which inaugurated the Coal Measure epoch in England, France, Belgium, Russia, the United States, South Africa, and Australia. They are frequently of considerable depth, and cover very large areas. The characteristic feature of the Millstone Grits of parts of England is their irregular stratification. They are often extremely false bedded, and consist of a series of interlacing lenticels of grit, and are very variable in thickness.[2]

The Loire Basin.—The basal breccia in the basin of the Loire consists of a confused mass of blocks of all sizes, some measuring a cubic metre.[3] They are fragments of local rocks usually angular and generally little rounded. There are occasionally semi-stratified bands of gravel and sand. It is overlain by a massive and true conglomerate containing pebbles as large as a child's head, but the majority are about the size of one's fist. The wedge-shaped layers which make up the conglomerate cross and recross one another, and are the work of irregular water courses which continually changed their direction while engaged in arranging and re-arranging the bottom over which they ran. Both towards the centre of the basin and at higher levels, the pebbles are much finer, and are enclosed in a matrix composed of fine sand particles. As it passes into a sandstone, the mica schist, gneiss, and granite particles disappear in the order of their resisting power to the prolonged trituration. The stratification at the same time converges in wedge-shaped layers and dipping planes towards the centres, where the grain is fine. The overlying fine-grained freestone is usually more definitely stratified.

The Belgian Coal Field.—M. Stainier has pointed out that the coarser material of the basal breccia has not been carried far, and has given rise to a type known as the Breccia without fine paste. A little further off the angular fragments have been eroded, and a fine paste formed, which is mingled with them. It passes by

[1] A. H. Green and R. Russell, "Geol. of Yorkshire Coal Field." *Mem. Geol. Sur. Eng. and Wales*, 1878, p. 12.

[2] W. Gibson, "Geol. of North Staffs. Coal Field." *Mem. Geol. Sur. Eng. and Wales*, 1905, p. 30.

[3] M. Grüner, "Études des Gites Mineraux de la France." *Bassin Houiller de la Loire*, vol. i., 1882, p. 20.

insensible gradation into a sediment more and more marked by the fine elements, and even into a compact limestone.[1] It appears that the fine sand and comminuted matter was simply washed out from among the larger stones and laid down further on.

The Appalachian Coal Field.—The Pottsville Conglomerate of Pennsylvania varies from a fine-grained sandstone to a coarse conglomerate made up wholly of smooth, rounded quartz pebbles, held loosely together by siliceous bond. The size of the pebbles varies from a pea to a walnut or goose's egg. As a formation it varies very much in thickness, and diminishes from 1,500 to 508 feet in 30 miles, and further still to 20 or 30 feet, and at the same time the rounded stones decrease in size.[2] The sandstones, shales, and conglomerates are usually cross-bedded, and the sandy beds between the pebbly layers are frequently steeply current-bedded.[3] The conditions of the Upper Old Red Sandstone were thus repeated after the quiet and still interval marked by the Mountain Limestone epoch.

South Africa.—The Massive Limestone, which, as we have seen, occupies the same geological horizon in South Africa and Australia, is followed by coarse conglomerates, which represent the Millstone grit period of England. The Waterberg beds of South Africa cover wide areas of the Transvaal, and are of great thickness. The sandstones vary in colour, and often present a remarkable degree of false bedding, with conglomerates at several horizons. They lie upon an eroded surface of the upturned older rocks, and are of torrential origin, having been formed by rapid sedimentation in water affected by variable currents, while there is evidence of igneous activity during the process.[4] The Pretoria conglomerates, which appear to be of the same age, contain cherts derived from the Limestone.

Australia.—The Gympie and Star formations of Australia are in every respect similar to those just described, and consist of conglomerates and cross-bedded sandstones, shales, and impure limestone derived from older rocks, and contain beds of igneous greenstone, volcanic ash, and lava beds, together with the remains of *Calamites*, *Stigmaria*, and *Lepidodendron*.[5]

Subaerial not Marine Denudation.—There is an important difference between these Millstone Grit conglomerates and the

[1] M. Stainier, "Mode de formation de la grande Brèche de Carbonifière." *Bull. Soc. Belge et Belgique*, vol. xxvi., 1910, p. 188.

[2] H. D. Rogers, "Appendix to Geol. of Clearfield and Jefferson District, Pa." *Geol. Survey Pa.*, H. 1875, p. 261.

[3] J. P. Lesley, *Summary Description Geol. of Pa.*, vol. iii., part 1, 1895, p. 1875.

[4] F. H. Hatch and G. S. Corstorphine, *Geol. of South Africa*, 2nd ed., 1909, . 205.

[5] R. L. Jack and R. Etheridge, *The Geol. and Palæontology of Queensland and New Guinea*, 1892, p. 205.

Lower Devonian ones, although their descriptions are so similar, and there are several reasons for the conclusion that the later ones were formed subaerially from the older rocks as distinct from the subaqueous formation of the earlier beds. While the Old Red conglomerates repose upon a disturbed and folded surface of older age, the Grits lie upon a less disturbed and channeled surface. In Iowa, for instance, the limestone is overlain by a few feet of marl, whose upper surface everywhere has been disturbed by running water, and in many places gullies have been made down into the limestone.[1] The basal rocks frequently rest upon an undulating surface formed by the unequal cutting away of the older rocks by the erosion, so that the coarse-grained conglomerate penetrates the lower beds obliquely.[2] At several widely separated parts of New Brunswick, the Coal measures rest upon the early Primary rocks, and it is certain that the intervening gap represents a great amount of denudation.[3] The distinction between the marine and subaerial erosion is illustrated by the following sketches :—

Fig. 18.—Two Sections, showing Comparison between Devonian and Lower Carboniferous Denudation.—1, Table Mountain Sandstone. 2, Steeply-inclined Slates. 3, Granite. 4, Lower Carboniferous Limestone. 5, Coal Measures. 6, Drift. (C. L. Griesbach, *Q.J.G.S.*, vol. lvii.; S. Calvin, *Geol. Sur. Iowa*, vol. xii.)

Volcanic Activity and Subaerial Denudation.—The crustal movements at this period were accompanied by contemporaneous igneous activity, which had been largely dormant in the limestone era. Evidence of this is forthcoming from Staffordshire, Derbyshire, and the Pennine axis, Australia, New Brunswick, and other parts of the world. The internal magma was becoming increasingly active, its influence was more and more felt at the surface, so that the seas were evaporated and the water held in suspension in the atmosphere. This went on to such an extent that M. Stainier believes that desert conditions prevailed in some places, and the exposed rocks were desiccated and split up into fragments, as they are in the Sahara.[4] This no doubt took place on higher ground, where a surface of loose

[1] C. R. Keyes, *The Classification of the Lower Carboniferous of the Mississippi*, 1892, p. 20.

[2] M. Grüner, "Études des Gites Mineraux de la France." *Bassin Houiller de la Loire*, vol. i., 1892, p. 51.

[3] L. W. Bailey, "The Carboniferous System of New Brunswick." *Geol. Survey, Canada, Ann. Rep.*, vol. xiii., n.s., 1900, p. 10 M.

[4] M. Stainier, "Mode de la Formation de la grande Brèche de Carbonifière." *Bull. Soc. Belge et Belgique*, vol. xxvi., 1910, p. 188.

breccia and sandstone was formed, and was accompanied by the continued evaporation of the seas in another.

How long this process continued, and to what extent the seas were dispersed into the atmosphere it is impossible to conjecture. The molten magma did not cease in its exertions, but rather increased in energy, and sheets of lava were poured out, so that a succession of such manifestations was accompanied by earth movements, and as the air was heavily charged with moisture, each upheaval of the surface tended to destroy the atmospheric equilibrium. Great volumes of water were condensed upon the rising land, and produced sheet flood and river erosion on a large scale.

The continued repetition of movements of elevation was thus accompanied by the frequent alternation of tranquil and disturbed conditions of aqueous sedimentation, while at the same time the extensive sheets of vesicular-igneous material interstratified with the sediments indicate the cause of the disturbances. As indicated by the accompanying illustration, erosion has taken place after the folding, so that the beds of sand fill the washed-out channels in slightly disturbed coal strata. Volcanic activity, earth motion, and denudation were thus acting in unison.

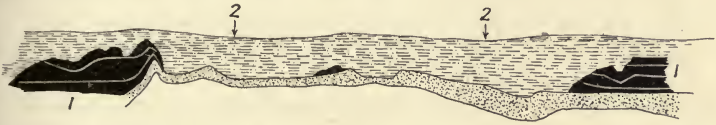


Fig. 19.—Washout in Coal Measures.—1, Coal Seam. 2, Sandstone in Wash-out. (Prof. R. F. Kendal, *Q.J.G.S.*, vol. xxvii.)

The Coal Measure sandstone of Iowa has everywhere been worn and channeled, often to a depth of more than 100 feet. In these narrow gorges and ravines more coal and shale have been laid down upon rounded and water-worn pebbles, and small boulders of sandstone mantled the old eroded surface. The vast sand beds had manifestly been consolidated and elevated above the sea for a considerable distance, and subjected to long-continued erosion.[1] They indicate the widespread and intense action of the denuding agency, for more than 150 feet of sandstone was largely removed and only remnants remain.

These wash-outs often form one broad hollow, but in the South Derbyshire Coalfield numerous confluent streams united together into one main channel, like the head waters of a drainage system.[2] Recently formed coal beds were eroded into channels, so that the roof of the coal seams are often the uneven bed of the sandstone produced by the currents. While again long ridge-like accumula-

[1] C. R. Keyes, *Class. of the Lower Carb. of Mississippi*, 1892, p. 20.

[2] Fox Strangways, "Discussion." *Quart. Journ. Geol. Soc.*, vol. lxi., 1905, p. 344.

tions of mud and sand have been piled up and form an uneven floor upon which coal and other debris was deposited.[1] They are of frequent occurrence in all coal fields, and sometimes several will run close together in long parallel lines, like the kames of Quaternary times.

Mechanical Sedimentary Cycles.—After one period of marked mechanical erosion and deposition of coarse conglomerate, the deluges filled up the depressions and submerged the low-lying estuaries, marshes, and plains, and thus put an end to the denudation. A well-ordered period of sedimentation then ensued. The heavier and larger pebbles and coarse sand first settled as a conglomerate, and then the finer sand upon the coarser, until only the silt which discoloured the water remained, together with the fragments of land vegetation strewed over and floating upon the surface. In time the water became clear, and a thick coating of fine clay was

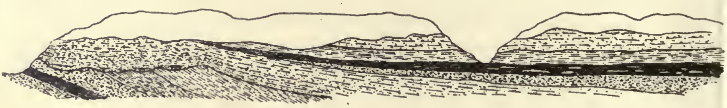


Fig. 20.—Section illustrating Disturbance, Erosion, and Redeposition of Coal Measures in Des Moines River, Iowa. (C. R. Keyes, *Geol. Sur. Iowa.*, vol. ii.)

spread out upon the sandy bottom, and the floating vegetation drifted upon the surface, and afterwards settled when the water receded.

These characteristics are frequently repeated in the sandstones and shales which form each mechanical cycle. Numerous opposing currents have built up complicated and interlaced sandy and shale beds. The sand was brought from one side and the shale from another.[2] In the vast majority of cases, the coarse and fine sandstone of the Yorkshire Coal Field shows the most pronounced cross-bedding.[3] The Pennant Grit of the Middle Coal of South Wales is generally highly current-bedded, and contains small rounded pebbles of quartz, ironstone, coal, and other Coal measure rock.[4] The shales which lie upon them are more regularly stratified, while the finest clays are perfectly unstratified.

These cycles of aqueous denudation, re-assortment of the debris, and graded sedimentation built up great depths of stratified rocks.

[1] J. Beete Jukes, "Geol. of South Staffs. Coal Field." *Mem. Geol. Sur. Gt. Br.*, 1859, p. 52.

[2, 3] A. H. Green and R. Russell, "Geol. of Yorkshire Coal Field." *Mem. Geol. Sur. Eng. and Wales*, 1878, p. 14.

[4] Aubrey Strahan and Walcot Gibson, "The Geol. of the South Wales Coal Field." *Mem. Geol. Sur. Eng. and Wales*, part 2, Abergavenny, 1900, p. 76. Walcot Gibson, "Geol. of North Staffs. Coal Field." *Mem. Geol. Sur. Eng. and Wales*, 1905, p. 34.

The alternation of the layers is by no means regular. The thickness of the seams varies, and in some coal fields they are more frequent than in others. The more profitable beds probably lie where the basins of collection were deepest and received the greater amount of vegetable debris from the neighbouring uplands.

The illustration, Fig. 20, shows two such cycles, the upper one of which was deposited upon the disturbed and denuded remains of the lower.

Changing Physical Conditions.—Over large areas in the Eastern States of North America the still and shallow water of the Mauch Chunk shales, which are the same age as the Mountain Limestone of England, there was a return to the deep water and strong currents in the Pottsville conglomerate. Throughout the coal measure series of North Staffordshire it is a rule for the grits and sandstones to lie regularly upon the softer strata.[1] Tranquil deposition was followed by more rapid sedimentation. The same remarkable sequence of events is portrayed in the French and Belgian coal fields. In normal times the waters were quiet and tranquil, and allowed the deposition of the ferruginous matter with which they were charged, but in times of swelling of rivers, currents and whirlpools were produced in the beds of lakes. Nothing hinders the conception of the existence of a veritably torrential regime, putting blocks in motion, and rolling pebbles into the lakes from the inundated banks.[2] These alternations are fully explained by the repetition of atmospheric cycles of evaporation and condensation as the surface rose and fell from time to time. Periods of earth movement producing erosion and rapid sedimentation alternated with intervals of stability, during which the finer silts were laid down.[3]

These torrential regimes mark the transition from one coal epoch to the next, and were separated from one another by wide intervals of time. As terrestrial stability was restored, vegetation once more thrived and spread itself across continental plateaux. Throughout these intervening periods growth was intense, and the material for the succeeding coal bed sprang up. In the stagnant water of wide-stretching lagoons, aquatic creatures lived and died and built up beds of limestone, which are now interstratified with the coal and shales. There were thus two well-marked phases of sedimentation, one distinct from the other, according to the occurrence of or freedom from physical disturbances.

Vegetation rapidly Entombed.—That these beds were not the ordinary result of river currents or of wave motion is proved by the condition and position of tree trunks often observed within the

[1] Walcot Gibson, "Geol. North Staffs. Coal Field." *Mem. Geol. Sur. Eng. and Wales*, 1905, p. 124.

[2] H. Deltenre, "Notes sur des cailloux roulées trouvés dans une couche de houille." *Soc. Geol. de Belgique, Annale* 35, 1907-8, p. 173.

[3] D. White, "Deposition of the Appalachian Pottsville." *Bull. Geol. Scc. Am.*, vol. xv., 1904, p. 280.

Coal measure sandstone. Tree trunks thrown up upon a beach by wave and tide would all be horizontal and parallel to one another and to the shore, while those floating in quiet water would all be horizontal, but not necessarily parallel to one another. Both of these conditions are departed from in the Coal measure rocks. Large stems and branches of plants lie frequently in all postures as regards the planes of bedding—horizontal, oblique, and perpendicular—and reveal in their broken condition and irregular mode of dispersion the sudden and tempestuous character of the currents which drifted and entombed them.[1]

It appears that the down-pouring deluge stripped the limbs from the trunks, pounded the surface soils, and formed a semi-liquid paste, which engulfed the trees and entombed them before they had time to rise to the surface. Sometimes, no doubt, they were snapped off by the force of the currents, borne along into some whirlpool of silt and debris-laden water, and came to rest in the positions in which they now lie, as the force of the motion ceased and settlement commenced. Had they been rolled before being entombed, the bark would have been much damaged, but it is not uncommon for the surface of the wood to be in a remarkable state of preservation.

Fresh-water Fauna in Coal Measures.—Beside all the evidence which attests this means of accumulation of much of the Coal measure strata, the fossil evidence distinctly favours it. "Above the Millstone Grit up to high in the Coal measure sequence, fresh-water mollusca occur as a prominent feature."[2] Fresh-water and estuarian horizons alternate with occasional marine bands, which in North Staffordshire recur up to 600 to 800 feet below the chief coal-bearing group.[3] These details are not confined to strictly limited localities, like fresh-water lakes of to-day, but are generally applicable to the whole of the Coal measure formation. The clear deep water which filled the lagoons after the precipitation and erosion, which marks each phase of the series, consisted of fresh water, and it remained calm and still for so long, at some intervals, that organic limestone rocks were deposited many feet in thickness by fresh-water mussels. The marine bands interstratified with fresh-water and estuarian sediments are believed to be due to incursions of the sea which flooded depressed areas during some stages of the disturbances, so that earth movement and atmospheric precipitation are both reflected in the faunal record.

Many of the sandstone beds are stained with carbonate of iron, which forms a red crust upon the surface, while the interior still

[1] H. D. Rogers, "Appendix to Geol. of Clearfield and Jefferson District." *Geol. Survey Pa.*, H. 1875, p. 261.

[2] W. Gibson, "Geol. North Staffs. Coal Fields." *Mem. Geol. Sur. Eng. and Wales*, 1905, p. 508.

[3] *Ibid.*, p. 42.

retains its blue colour. The colouring is therefore not original, and is due to the exposure of the stone after deposition and the percolation of fresh-water. It therefore confirms the other evidence that after deposition in deep water the sandstone was exposed to the air, and overrun by currents of fresh-water, and was afterwards covered up by more beds of graded mechanical sediment.

Methods of Accumulation of Coal.—The repetition of these cycles of atmospheric precipitation and condensation is also seen in the beds of coal themselves. Geologically speaking, no sooner had the deluge of fresh water transgressed the land than it commenced to gradually evaporate, and eventually left the fine clay still above the water. These clays are almost always dotted with roots and stools of coal forest trees, still remaining in the original position of growth. The soils propagated a dense forest vegetation, which thrived for a long period, until it was finally overwhelmed in another cycle.

The almost universal association of beds of underclay and stools with seams of coal has led many geologists to infer that the coal is the accumulation of the decayed remains of vast quantities of vegetable substance which grew in the soil upon which it now lies. Sir J. W. Dawson said that true coal is the flattened bark of trees intermixed with the leaves of ferns, plants, and other herbaceous debris, all having manifestly grown where we find them.[1] But, while this may be true for many beds, it does not fully comply with all the conditions observed in many seams, and as there are so large a number in every coal field, there is room for the operation of other causes.

Another school of geologists affirm that the beds are composed of drift wood, which has been carried to its present position by currents of water, and since many of the sands and shales are interspersed with much fragmentary and fossil wood of the same sort that composes the coal, it is clear that the same deluges which accumulated the sands and clays also drifted the great masses of vegetation and assembled them in lenticular beds.

This theory is, moreover, fully in accord with the mode of formation of the associated sands and shales. They were laid down in the order of the specific gravity of the particles after each period of erosion and submergence. In this order the vegetable matter floated upon the surface after it had been swept from neighbouring land where it grew. When evaporation again ensued, the water subsided from beneath it, and allowed it to settle upon the surface of the clays not far from where it had grown.

The vegetation was divided and hashed, and with the movable rock was stirred up and jumbled together by the agitated water and intimately mingled.[2] As calm was re-established they were

[1] Sir J. W. Dawson, *Acadian Geol.*, 4th ed., 1891, p. 138.

[2] M. Stainier, "De la formation des gisements houillers." *Soc. Belge et Belgique*, Bull. xxii., 1906, p. 113.

precipitated to the bottom of the water in a definite order determined by the relative density of the materials.

Through the instrumentality of these cycles of erosion, sedimentation, and forest growth a great series of alternating sand, shale, clay, and coal was built up. In the South Joggins section of the New Brunswick coal field there are over 100 seams of coal overlying beds of clay with the roots of stigmaria in their natural position of growth within a total thickness of 3,240 feet.

It is the beds of coal which were accumulated in this way, remnants of which have been preserved from subsequent denudation, that now form the principal sources of coal supply. As each successive layer was entombed, it was preserved in hermetically sealed chambers, from which the moisture was afterwards evaporated. As layer was added to layer and bed to bed, the lowest ones were compressed and carbonised into solid masses by the influence of the heat, pressure, and moisture.

Duration of Coal Epoch.—The time occupied by the events described in this chapter cannot be over-estimated. Each of the numerous beds of coal probably required a length of time comparable with the whole of the historic period, and the same may be said of the frequent layers of limestone which were laid down in the inland seas and wider oceans. The mechanical cycles only represent the shorter periods of transition between the epochs of forest growth. The multiplication of coal seams may thus require a period equal in extent to either of the earlier primary epochs.

General Effect of Repeated Cycles.—The causes which were responsible for the initial stages of the sequence in the Millstone Grit were also effective in producing the repetition of those phenomena. Each uplift resulted in aqueous precipitation and denudation. The igneous activity which occasioned each uplift was as often checked, but asserted itself after each long interval of repose, evaporated the water, dried up the surface of the land, and upheaved it once more. In this way cycle followed cycle, and the earth's surface was greatly modified. The surface features were rendered peculiarly uniform with, perhaps, nothing but low-lying flats visible over the whole horizon.

The surface of the earth does not seem to have been divided into continents and oceans in the present sense. A greater uniformity of surface gave unusual facilities for the migration of species from one place to another. This was the case during land conditions and during submergence. The proportion of identical species of the coal flora of many continents is so large as to necessitate an extraordinary lack of barriers to the freest migration.[1] The only possible explanation of the homogeneity of types of the early vertebrates is the freedom of communication and migration. The per-

[1] David White, "The Upper Paleozoic Floras: their Succession and Range," in Bailey Willis and R. D. Salisbury's *Outlines of Geol. Hist.*, 1910, p. 147.

sistence and wide extent of like climatic and fresh-water conditions permitted, for instance, the migration of snake-like forms from Ohio to Ireland and Bohemia without material modification of structure.[1] That is to say, that during land conditions there was an absence of ocean barriers, and during fresh-water submergence there were no land barriers, which points to a more uniform configuration of surface at the close of the Primary ages.

[1] S. W. Williston, "The Faunal Range of the Early Vertebrates," in Willis and Salisbury, *loc. cit.*, p. 166.

CHAPTER XIV.

THE PERMIAN TRANSITION.

Disturbance of the Earth's Crust—Uplifting of Ocean Bed—Compression of Strata—Igneous Outbursts—Faulting—Erosion—Origin and Distribution of Permian Rocks—Permo-Carboniferous of New Brunswick—Cause of Permian Denudation—Compared with Alpine Glacial Beds—Glacial Origin of Midland Permian Breccias discussed—Glaciation in other Parts of the World—A Permian Ice Age—Conclusion of Primary, Sedimentary, and Atmospheric Cycles.

As soon as we leave the land surface of the ancient Primary earth, as represented by the Coal measures, with the alternate periods of forest growth, aqueous deluge, and sedimentation, and enter the next series of rocks, a great transformation has taken place. The changes were very marked and affected the physical geography, the climate, and the life of sea and land. It is difficult to say in which sphere the transition was felt in the severest degree.

Perhaps in no period of the history of the rocks is there a more striking change than between the Carboniferous and the Permian. The one indicates marshy plains with abundant plant life and a humid atmosphere ; the other points to tracts of upland and lowland with a dry climate and scanty signs of life.[1] In place of the wide stretching marine lagoons and seas, the water area was restricted to few fresh-water basins. The process of sedimentation which had proceeded continuously throughout the whole of the Primary epoch almost ceased. When it recommenced the earth builders were nearly all new types. The mild and humid climate gave place to severest winter's cold. The uniform conditions of the older era changed over to the varied condition of the new. The freedom of migration of the fauna and flora of the Carboniferous epoch was checked, and evolution was confined to strictly limited areas.

All these were not common to the whole globe, and different parts endured the transition in differing degree, while in favoured localities little, if any, change was felt, and life pursued its wonted avocation little impeded. Neither was the revolution restricted in time. It was an epoch of change, not a momentary transition.

The changes in the physical geography of the earth's surface were denoted by : 1, disturbance of crust ; 2, uplifting of the ocean bed ; 3, contortion of strata ; 4, igneous outbursts ; 5, faulting ; and 6, erosion of the surface. Each of these phenomena will be treated separately.

[1] J. E. Marr, *An Intr. to Geol.*, 1905, p. 176.

1. **Disturbance of the Earth's Crust.**—Every geological work of importance speaks of considerable movements which took place at this time over wide regions. "The order of the ancient sedimentary succession was very widely, though not universally, interrupted, and all the strata previously spoken of were so disturbed as to produce a prevalent break or discordance between the Carboniferous deposits and those which succeeded them." [1] American geologists have shown that the period of the disturbances in the New World

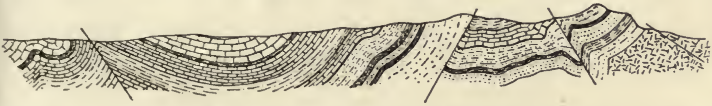


Fig. 21.—Folding and Faulting in Cambrian and Ordovician Rocks of the Appalachian Region, Tennessee. Section, 10 miles in length. (A. Keith, *U.S. Geol. Sur., Atlas Folio* 151.)

took place at the same epoch. The most important of all the geological changes in Eastern America was the disturbance which tilted up to the surface the great beds of iron ore and the succeeding accumulations of the Carboniferous period.[2] The excessive degree of these seismic changes is apparent in many local cliff sections in both hemispheres, where the older rocks have been lifted bodily from their original horizontal position, and are now steeply inclined or even vertical, and their eroded edges are covered with later rocks. The general result of these displacements was that the continents

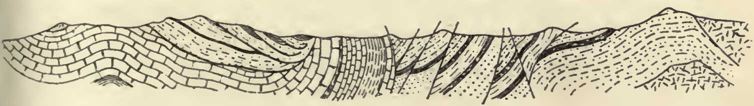


Fig. 22.—Folding and Faulting in Cambrian and Ordovician Rocks of the Appalachian Region, Tennessee. Section, 10 miles in length. (A. Keith, *U.S. Geol. Sur., Atlas Folio* 151.)

were rendered slightly more protuberant, by being mildly arched and warped throughout the larger part of their area, on account of the sharp folding of the internal shell of the earth.[3] The older beds were thrown into synclinal and anticlinal bends, often very abrupt, before the deposition of the Permian. The movements which took place in all continents during the closing epoch of the Primary and the initial epoch of the Secondary were pronounced and prolonged throughout China,[4] India, and Turkestan.[5]

[1] Sir R. I. Murchison, *Siluria*, 1867, p. 308.
[2] Sir J. W. Dawson, *Acadian Geol.*, 4th ed., 1891, p. 666.
[3] T. C. Chamberlain and R. D. Salisbury, *Geology*, vol. ii., 1905-6, p. 656.
[4] Bailey Willis, *Research in China*, vol. ii., 1907, p. 89.
[5] R. W. Pumpelly, *Exploration in Turkestan*, 1903, p. 161.

Events of a revolutionary character moved quickly in Northern India, where the whole order of things was changed, "and peaceful marine sedimentation gave place to volcanic outbursts on so grand a scale that there is but little doubt that great accompanying changes of level of land and sea must have occurred, not only as a consequence of the extraordinary extravasation of molten magma, but also as a prelude to it."[1]

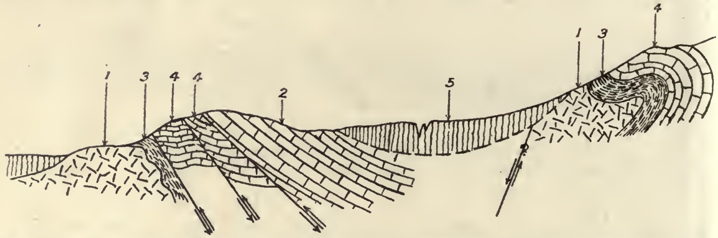


Fig. 23.—Folded Cambro-Ordovician with Overthrust Dolomite, probably pre-Cambrian.—1, Granite. 2, Pre-Cambrian? 3, Cambrian. 4, Ordovician. 5, Löess. (Bailey Willis, *Research in China*.)

2. **Uplifting of the Ocean Bed.**—"At the close of the Carboniferous period, the whole of the surface of Ireland was but little elevated above the ocean. The result of these movements would be to raise the domes and arches high into the air, and to slightly depress and submerge the surrounding tracts of nearly level strata."[2] "The elevation was only one phase of a vast terrestrial movement, which was extended over whole continents, and has affected plains as well as high grounds."[3]

The continents, as we now know them, did not receive their present configuration at this time. In some parts of the earth's surface extensive plateaux were upraised, while igneous intrusions formed more local elevations. Some of the mountain chains of the earth were brought into being. The mountains of the Rhine, the Ardennes, Westerwald, and Taunus, the Vosges and Black Forest, and the Hartz, together with those of Saxony and the Sudelets experienced a great and general folding towards the close of the Carboniferous period.[4] The coast of the Atlantic from the mouth of the Shannon to Finisterre and the mouth of the Loire is formed by the breaking off and subsidence of a great mountain chain, which acquired the greater part of its elevation at the same time. The Reeks of Killarney, the rocky coast of Brittany, the Granite intru-

[1] C. S. Middlemiss, "Revision of the Silurian-Trias Sequence in Kashmir." *Geol. Sur. India, Record*, vol. xl., 1910, p. 210. C. L. Griesbach, "The Sequence of Formation in Spiti." *Loc. cit.*, vol. xxii., part 3, 1889, p. 164.

[2] E. Hull, *Physical Geol. and Geog. of Ireland*, 2nd ed., 1891, p. 190.

[3] Sir A. Geikie, *Geological Sketches at Home and Abroad*, 1882, p. 332.

[4] Eduard Suess, *The Face of the Earth*, tr. by H. B. A. Sollas, vol. ii., 1904, p. 96.

Fig. 1.—Folded Upper Silurian Sandstone and Shales. Maryland.

Fig. 2.—Anticlinal fold in Sandstone and Limestone. West Virginia.

United States Geological Survey Photographs.

sions of Devon, the Eddystone rock, the Lizard, and Prawl Point are what remains of the ruins of a mighty mass of lofty mountains.[1] This system probably sent ridges far up the English Channel. Some geologists think that the Primary continents existed all across the North Atlantic, and linked Scandinavia, Greenland, and Canada together.[2] The Pennine Chain and the Mendip Hills in England and the Ural Mountains of Russia are of the same age. The great depressions which had occupied the seas of Carboniferous times were broken up, and new ranges of hills were raised across them, and a new set of physical features was formed.[3] The Welsh mountains and the Highlands of Scotland and Scandinavia, as well as the Laurentian plateau of Canada, no doubt experienced a further uplift. The relative altitude of the physical features was greater than now. They have been excessively denuded by the destructive agencies which have since come into play, while some have entirely disappeared. None of the greatest mountain chains date back so far as the Permian times.

The period we are considering was primarily one of continental uplift. It was responsible for such features as the great platform

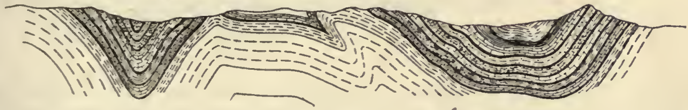


Fig. 24.—Folded Coal Seams and Sandstone in Pennsylvania. (J. P. Lesley, *Summ. Desc. Geol. Pa.*, vol. iii., part 1.)

of Eastern Siberia, which covers an area occupying 20° of latitude, and stretches from the Yenesei River to the Lena. "This great platform is to some extent formed of absolutely horizontal beds" of Primary age. The outskirts show evidences of folding and disturbance.[4]

3. **Compression of Strata.**—The regional uplift and disturbance of some areas was accompanied by folding and contortion of the rocks in others, which were produced by lateral thrust. "The rocks of the South Foreland and the Start Point are at least 60 to 70 miles nearer to each other now than when the mountain building throws began."[5] That is to say, the rocks have been compressed by movements of the terrestrial crust into about half the space originally occupied by them. The lateral pressure which produced this state of things was intense. In the great eruption of the granite of Dartmoor, the derangement of the Western portion of South Devon

[1] E. Suess, *loc. cit.*, vol. ii., p. 89.
[2] J. A. Jukes Browne, *Building of British Isles*, 3rd ed., 1911, p. 188.
[3] Do., *loc. cit.*, p. 195.
[4] Eduard Suess, *loc. cit.*, vol. iii., p. 17.
[5] A. W. Clayden, *The History of Devonshire Scenery*, 1906, p. 60.

and the adjacent parts of Cornwall is so great that the Lower Silurian rocks overlie the Devonian. These movements took place in "the great east and west lines of flexure belonging to the period between the Carboniferous and the Permian."[1] They continued into Ireland, and belong to a system which influenced the Primary strata all over the South of England and Wales and the borders of France and Belgium, to, and even beyond, the valley of the Rhine.[2]

This deformation was a protracted process, and was in progress at the base of the deeper sections during the lesser movements which took place during the Coal epoch, long before the more general upheaval. The folding was in that case due to similar causes which were in operation in the Devonian period. This would fulfil the requirements of Prof. Willis' hypothesis that folding takes place during deposition, and ceases when the deformative movements commence.[3] The more ancient rocks, the recently contorted beds, as well as the newly formed and less disturbed strata, were uplifted together at this time.[4]

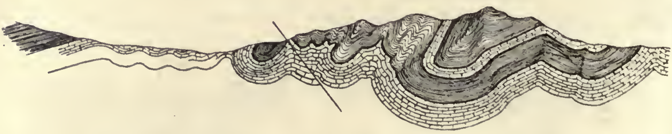


Fig. 25.—Folded and Compressed Cambrian and Silurian Rocks in New York. Section, 7½ miles. (T. N. Dale, *U.S. Geol. Sur. Ann. Rep.*, vol. xiii., part 2.

4. **Igneous Outbursts.**—Volcanic activity abounded in the beginning of the Permian era. There is evidence of this throughout Central Germany and in many other parts of the world, as well as in Great Britain. It is marked by granitic intrusions, dykes, and lava flows. Were the coating of later strata which covers the old land surface removed, there is no doubt that our knowledge of these events would be considerably extended. Volcanoes belched forth scoriæ and dust on a great scale, and spread them out on the bed of the Triassic Sea, and currents of lava were poured forth. It sometimes forms lofty precipices and perpendicular walls of columnar basalt several hundred feet in height, adorned with buttresses, outlying towers, and pinnacles.[5]

There are a large number of dykes in Carmarthenshire, sometimes injected along lines of fault, which were probably formed between the Carboniferous and Permian.[6] Side by side with the great earth

[1] Sir R. I. Murchison, *Siluria*, 1867, p. 274.
[2] E. Hull, *Physical Geol. and Geog. of Ireland*, 2nd ed., 1891, p. 170.
[3] Bailey Willis, "Mechanics of Appalachian Structure." *Geol. Sur. U.S. Ann. Rep.*, vol. xiii., part 2, 1892, p. 281.
[4] Bailey Willis, *loc. cit.*, p. 278.
[5] Sir J. W. Dawson, *Acadian Geol.*, 4th ed., 1891, p. 93.
[6] A. Harker, *Bala Volcanic Series of Carnarvonshire*, 1889, p. 107.

movements throughout Europe the eruption of large igneous masses took place.[1] The Panjal traps of Northern India attain the great depth of from 10,000 to 15,000 feet, and consist of lava flows and agglomerates.[2]

Faulting.—The crust of the globe suffered a considerable amount of faulting or fracture at the same time that the disturbances were in progress. There is direct evidence to show that faults and flexures are contemporaneous and due to the same cause. The crustal distortion was of an exceedingly complicated character, as may be seen from the various illustrations. The forces which were in operation for an extended period varied in magnitude and direction. Gentle folding was effected without fracture, but frequently the upward thrust was so severe that the shearing resistance of the strata was overcome, and it gave way along planes of least resistance,

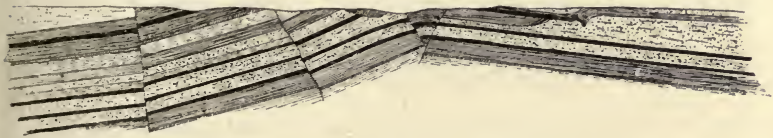


Fig. 26.—Disturbed and Faulted Coal Beds in the Silécie Coal Basin. (Burat.)

and masses of stratified material were moved bodily forward or upwards with relation to those from which they had been sheared. At another extreme, complicated fault systems were produced as if large areas of level strata had given way by sinking, having behaved more like a brittle substance than plastic material. Faulting and thrusting were thus apparently due to variation in the extent of upheaval and to subsequent subsidence.

6. **Erosion.**—The denudation of the uplifted Carboniferous strata was one phase of the Permian transformation, and is well seen in the accompanying diagrammatic section across the Belgian Coal field, where highly inclined, disturbed, and faulted coal beds were eroded to an almost level surface, upon which newer deposits were accumulated. Towards the close of the Carboniferous period, possibly also within early Permian times, the terrestrial disturbances increased so much that the Carboniferous system was, in many, if not in most districts of Great Britain, upheaved so as to be exposed to denudation.[3] There is abundant evidence that an enormous mass of material had been denuded before the Triassic period commenced in South Wales. The thickness of rock removed amounted

[1] E. F. H. Kayser, *Text-book of Comparative Geol.*, tr. by P. Lake, 1893, p. 128.

[2] C. S. Middlemiss, "Revision of the Silurian-Trias Sequence in Spiti." *Geol. Sur. India, Record*, vol. xli., 1910, p. 133.

[3] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1903, p. 1048.

to 7,000 feet in some places.[1] A vast amount of erosion was accomplished at this time in parts of Northern India and Tibet, and the Upper Carboniferous sedimentary rocks were eroded down to the basal quartzite.[2]

Origin and Distribution of Permian Rocks.—The denudation of the uplifted land surface accounts for the origin of the Permian fragmental rocks. The interval recorded by them is one of enormous length. It is represented in Texas by 5,000 feet of sedimentary clays and sandstones.[3] The disturbances and earth movements with which it commenced were followed by the erosion of the uplifted land. The materials produced in this way were spread out

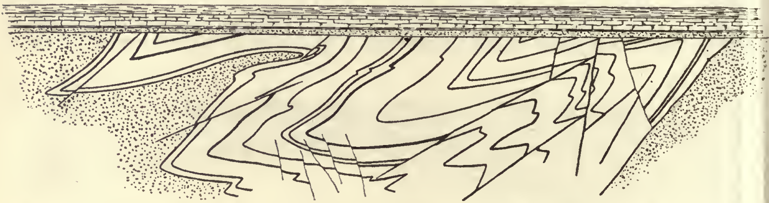


Fig. 27.—Denudation of Folded and Faulted Coal Measures in Coal Field du Nord. (Burat.)

again to form the Permian boulder beds. The deposits of Silurian, Devonian, and Carboniferous age, which before the uplift remained spread out in wide horizontal and slightly broken masses over Russia in Europe, were thrown up in the Ural Mountains, out of whose debris the Permian deposits were formed.[4]

Permo-Carboniferous of New Brunswick.—The Permian of New Brunswick was deposited in a number of synclinal hollows formed between the upward thrusts of the older Carboniferous rocks. The lower beds consist of an immense mass of conglomerate, some 1,600 feet in thickness, and containing boulders and pebbles of all sizes up to 3 feet in diameter, derived from the Carboniferous strata, and were denuded from them. These boulder beds line the hollow in which they lie. Succeeding them, and resting in the hollow formed by their upper surface, is what is known as the Upper Coal formation. The arrangement of these beds is similar to those in the true coal, but points to a somewhat different mode of formation. They were accumulated at a period subsequent to the disturbances which took place at the close of the Coal epoch proper, as they do

[1] Aubrey Strahan and T. C. Cantrill, *The Geol. of the South Wales Coal Field*, part 6, Bridgend, 1904, p. 23.

[2] Col. S. G. Burrard and H. H. Hayden, *Geol. and Geog. of Himalaya Mtns. and Tibet*, 1907-8, p. 234.

[3] W. B. Scott, *Introduction to Geol.*, 1897, p. 430.

[4] Sir R. I. Murchison, *Siluria*, 1867, p. 362.

not appear to have participated in the folding and fractures which then took place.[1] Although they contain many of the same fossils, and consist of the same materials as the earlier coal beds, well-preserved fossils are comparatively rare, and no erect plants are found.[2] These beds are often of great thickness and very productive, whereas the older are thin and frequently unworkable.

The mode of formation of this series appears to be as follows :— The coarse " conglomerate affords evidence of the extensive denudation of the Lower Carboniferous before the deposition of the productive coal measures," which agrees in time with the erosion in other regions. The older rocks, together with the interstratified beds of coal and the dense surface vegetation, were eroded and carried into the basin-shaped hollows which were already filled with water. The heavier material now forming the conglomerate immediately sank to the bottom, while the carbonaceous matter and vegetation floated at or near the surface. The hollows were in time filled with dense masses of broken and mangled vegetable matter, which eventually consolidated, and now forms valuable coal seams.

Cause of Permian Denudation.—The erosion which succeeded the epoch of disturbance was somewhat different in character in the northern and southern hemispheres. South America, South Africa, and Australia experienced a severe degree of glaciation, and although there is evidence of similar nature in the Permian of Europe, it is not so well marked. Decided glacial evidence in the northern hemisphere is confined principally to India. The components of the northern Permian conglomerates are more water-worn than glaciated, and may point to the recurrence of the forces which were in operation in the Coal epoch. On the other hand, there is good reason for thinking that glaciers were prevalent and that the moraines associated with them were re-assorted by fluvio-glacial rivers as the ice melted, so that the glacial scoring upon the pebbles was obliterated in a large measure.

The glacial denudation in southern latitudes and in India was due to enormous masses of ice, which clothed the uplifted continents and planed them down, and in a great measure to fluvio-glacial erosion, owing to the continual melting of the ice. This conclusion has been come to through the study of existing glaciers, and by comparing the phenomena peculiar to the Permian rocks with the results of ice motion at present in progress.

Compared with Alpine Glacial Beds.—Alpine glaciers remove inequalities in the surface of the ground over which they glide, and cut deep groves in the harder rocks, which is termed striation. The angular stones, sand, and rock meal removed in this way are carried along the bottom by the streams of water as the ice melts or are

[1, 2] Sir J. W. Dawson, *Acadian Geol.*, 4th ed., 1891, pp. 318, 322.

pushed forward by the motion of the ice, and deposited in heaps at the margin of the glacier. Large boulders which become encased in the bottom of the ice are carried along with it, and become striated in the same way as the underlying rocks. They are eventually liberated, and form a large part of the terminal moraines.

Glacial Origin of Midland Permian Breccias discussed.—Professor Ramsay was the first to notice the similarity between the Permian rocks and the more recent Glacial Till and Alpine moraines. "So completely indeed," he said, "does the whole deposit resemble the Post Pliocene boulder clay, that I have no doubt that there was a glacial episode during part of the Permian epoch." In some cases the smooth surface of the stones still retain striations "identical in character with those found in ordinary boulder clay as made by modern glaciers." [1]

The evidence upon which the glacial origin of these breccias was based has since been contested, and the apparent striations upon the boulders attributed to subterranean causes. At the same time, the opinion is still held that not a few of the striated fragments are such as would unhesitatingly be accepted as glacial if they were found in a recent moraine or in a Pleistocene boulder clay.[2] Criticism has also been brought to bear upon Prof. Ramsay's conclusion, because he traced the origin of the included pebbles from distant sources to the north, whence they had been brought by the glaciers. Recent investigation has proved this to be erroneous or unlikely, and it has been concluded that they are either of more local origin, or have been derived from the south-west of their present position,[3] but rather than controverting the original conclusion this strengthens it, for the debris forming the ground moraines of glaciers has not usually been carried for great distances. The Glacial Till of the early Quaternary ice age is of strictly local origin, so much so that it is principally composed of fragments of the rocks immediately beneath it, and where the Till passes from one rock formation to another the change is distinctly noticeable in the overlying deposits, and the distinction is often comparatively abrupt.[4] It has also been proved that glaciers moved southwards in South Africa in the Permian.[5]

It may also be mentioned that the glacial origin of some of the older breccias is based as much upon inference as upon actual

[1] Sir A. C. Ramsay, *Geol. of Gt. Britain*, 1878, p. 143.

[2] R. D. Oldham, "A Comparison of the Permian Breccias of the Midlands with the Glacial Deposits of India and Australia." *Quart. Journ. Geol. Soc. London*, vol. l., 1894, p. 467.

[3] Wickham King, "Permian Conglomerates of the Lower Severn Basin." *Quart. Journ. Geol. Soc.*, vol. lv., 1899, p. 126.

[4] C. T. Clough and Associates, "The Geol. of East Lothian." *Mem. Geol. Sur. Scot.*, 1910, p. 171.

[5] W. M. Davis, "Observations in South Africa." *Bull. Geol. Soc. Am.*, vol. xvii., 1906, p. 413.

evidence of ice marking upon the stones. It is usual to speak of the Quaternary Drift as glacial, whereas there is frequently no trace of ice action in it. Since, therefore, both fact and inference strongly support the presence of ice fields in England in Permian times, there are good grounds for accepting Prof. Ramsay's original conclusion. There is, moreover, evidence that these glaciers continued for a long period, as some of the pebbles in the Trias in the South-west of England have distinct glacial markings.[1]

Glaciation in other Parts of the World.—Were the English Permian the only source of evidence of the glacial origin of the rocks of this period, it would be insufficient to base a general conclusion upon, but in other localities where they have been searched they are so clearly of this nature that, in spite of the doubts which have been thrown upon the glacial origin of the markings on the boulders, it is evident that they must be attributed to some phase of the glacial episode.

Unlike the recent glaciers, which remain in particular localities for long periods, the Permian ones, as we shall see later, continually receded northwards, and were all the while melting away, so that glaciation was followed by aqueous re-assortment of the angular fragments, which rounded them into gravel, and many of them lost their ice scratchings, while, as in the Permian of Arran, Penrith,[2] and Shantung,[3] current bedding was sometimes produced in the sandstones.

The Permian of other parts of the world have now been closely investigated, and it is shown that many continents experienced the refrigeration, which brought on glacial accumulation. The Rothliegende, which is the representative of the Permian in Germany, and extensively exposed, has been attributed to glacial origin.[4] Striated nodules recorded by Murchison in the Permian grits of Russia may point to similar causes in operation there.[5] The Karoo formation of South Africa is similar in every respect. "Round the margin of the Karoo outliers, the old land surface, dating back as far as the Carboniferous time, still preserves astonishingly clear traces of ice action." [6] Where the Till has been removed, the striated hummocky mounds, which in northern latitudes are known as *roches moutonnés*,[7] are to be seen, which exactly reduplicate the ice work of the Alps and other glaciated regions. The fragments of which this conglomerate is composed, both large and small, are confusedly heaped together, and frequently show stria-

[1] H. B. Woodward, *Geol. of Eng. and Wales*, p. 231.

[2] J. A. Jukes Browne, *Building of British Isles*, 3rd ed., 1911, pp. 206-8.

[3] Bailey Willis, *Research in China*, vol. ii., 1907, p. 81.

[4] G. F. Wright, *Ice Age in North America*, 2nd ed., 1911, p. 485.

[5] *Geol. of Russia and Ural*, p. 195.

[6] E. T. Mellor, "Study of the Glacial Conglomerate in the Transvaal." *Quart. Journ. Geol. Soc.*, vol. lxi., 1905, p. 682.

[7] A. W. Rogers, *Intr. to Geol. of Cape Colony*, 1905, p. 154.

tions. "It is unmistakably a glacial deposit." The Karoo formation covers the greater part of Cape Colony, extends through Pondoland, Natal, Zululand, and far North into the Transvaal.[1] The Talchir rocks of India "cover an enormous tract of country, extending from the flanks of the Rajmahal Hills to the Godavari River, and from Lower Bengal to Nagpur and Chandra,"[2] and, therefore, occupy an area of about 150,000 square miles. Some of the larger boulders have smoothed and striated surfaces, and the Limestone underlying it is in some places polished, scratched, and grooved. The pebbles in the Speckled Sandstone of the Salt Range in India contain angular and sub-angular blocks of hard crystalline rock, which still preserve the facetted, striated, scratched, and polished surfaces imprinted upon them by the movement of glaciers.[3] They are sometimes scattered through sandy shales, and some are 750 miles north of the nearest rocks to which they show any analogy.[4] This points to transport by icebergs which broke away from the main body of ice, and floated away, possibly from the areas just referred to.

The glacial deposits of Australia reach enormous proportions, and are found through no less than 30° of latitude and 25° of longitude. There are ten successive boulder beds in 2,000 feet of strata.[5] Some of the erratics are 30 tons in weight, and nearly all are beautifully glaciated and facetted. Large boulders are sometimes embedded in fine silt, and 30 miles from the nearest parent rock.[6] They could not have been transported by the same agency as the silt in which they were embedded, and must have been carried by floating ice and deposited as it melted.[7]

A Permian Ice Age.—All observers who have studied the Permian Breccias of India and Australia in the field, have, without exception, come away convinced that ice is the only agent capable

[1] D. Draper, "Notes on Geol. of South-eastern Africa." *Quart. Journ. Geol. Soc.*, 1894, p. 555.

[2] H. B. Medlicott and W. T. Blanford, *Manual of the Geol. of India,* part 1, 1879, p. 110.

[3] C. S. Middlemiss, "Geol. of the Salt Range of the Punjab." *Geol. Sur. India, Records,* vol. xxiv., part 1, 1891, p. 22.

[4] R. D. Oldham, *Manual Geol. of India,* 2nd ed., 1893, p. 120.

[5] T. W. Edgworth David, "Evidence of Glacial Action in Australia in Permo-Carboniferous Time." *Quart. Journ. Geol. Soc.*, vol. lii., 1896, p. 300.

[6] T. W. Edgworth David, "Evidence of Glaciation in the Carboniferous and Hawkesbury Series, N.S.W." *Quart. Journ. Geol. Soc.*, vol. xliii., 1887, p. 190.

[7] For correlation of the Glacial deposits of the Southern Hemisphere with the Permian of the Northern Hemisphere, see W. King, "Discovery of Trilobites in the Salt Range." *Geol. Sur. India, Record*, vol. xxii., part 3, 1889, p. 157. C. S. Middlemiss, "Revision of the Silurian-Trias Sequence in Kashmir." *Geol. Sur. India, Record*, vol. xl., part 3, 1910, p. 210. A. Bertrand, "Les Phenomene glaciaires de l'époque Permo-carbonifière." *Soc. Geol. du Nord Annale,* vol. xxxviii., 1909, p. 109. A. W. Rogers and A. L. Du Toit, *The Geol. of Cape Colony*, 2nd ed., 1909, p. 243.

of producing the effects which they have seen.[1] "The evidence now accumulating from South Africa, India, Cashmere, Australia, and Brazil,[2] seems to point to some general operation on a gigantic scale in the Southern Hemisphere at the close of the Carboniferous or in the Permian period, whereby boulder beds were produced and rocks *in situ* were polished, striated, and grooved. The assemblage of these peculiar features so exactly reduplicates the familiar phenomena of the Glacial period, that it is hardly possible to resist the conclusion, which has been reached by those who have studied the details on the ground, that it proves the occurrence of a former ice age in late Primary times, which rivalled in extent and seems to have surpassed in magnitude of its deposits, the glaciation in the Northern Hemisphere." [3] North of Godwana Land, in Tibet, the denudation produced ordinary conglomerates, sandstones, and shales, which are followed by Triassic limestone of great depth. The absence of Glacial Till seems to show that the Indian glaciers were confined to a Highland system, and that ice-bound seas stretched away northwards as far as the Polar ice, in which subsequent sediments were laid down, as in Alaska [4] and Spitzbergen.

It is evident that the Permian glacial episode was of long duration, and the ice which clothed the continents was almost universally extended. There are no means of estimating the depth of the ice which enveloped the earth, but from the details which are discussed in subsequent chapters, the *mer de glace* proves to be the most extensive and massive yet known to have existed upon the earth.

The events so far described and recorded by the Permian rocks are the continental upheaval, which was accompanied by rock folding, contortion, and faulting, and the various manifestations of volcanic activity which produced intrusions, dykes, and lava flows. The last phase of this remarkable sequence of events was the glacial episode. The uplifting of large continental areas of the sea bed was followed by aqueous and glacial denudation.

Conclusion of Primary, Sedimentary, and Atmospheric Cycles.— The close of the Primary epoch was the conclusion of another sedimentary and volcanic cycle, and the consequent atmospheric cycle. The moisture with which the Carboniferous atmosphere was charged condensed at the time of the uplift. The ice which was formed eventually melted and another sedimentary cycle commenced. The uplift and subsequent Permian glaciation was followed by

[1] R. D. Oldham, "A Comparison of the Permian Breccias of the Midlands with the Upper Carboniferous Glacial Deposits of India and Australia." *Quart. Journ. Geol. Soc.*, 1894, p. 469.

[2] David White, "Permo-Carboniferous Climatic Changes in South America." *Am. Journ. Geol.*, vol. xv., 1907, p. 618.

[3] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1903, p. 1060.

[4] T. W. Stanton and G. C. Martin, "Mesozoic Section in Cook Inlet and Alaska Peninsula." *Bull. Geol. Soc. Am.*, vol. xvi., 1905, p. 403.

aqueous erosion as the ice melted, and combined with the ordinary atmospheric decay to form another evolutionary cycle of uplift and denudation. The processes which were responsible for the slow building up of the ancient pre-Cambrian and earlier systems were in this way repeated in the Primary, and it is upon the fact of the abundant precipitation required for the formation of Glaciers that the principle of the Atmospheric cycle is based. The only known source of glacial ice is the heavy fall of snow in high altitudes and colder regions. The required moisture is carried there from warmer latitudes by winds and air currents. Rain-storms are due to the same causes, and it is evident that upheavals of insufficient magnitude to produce snow-storms will cause heavy rains, such as are required to explain the formation of the Coal measures.

This theory has a substantial basis in fact, for "the rain-storm which caused such havoc in Darjeeling in 1899, at an elevation of 16,000 feet, assumed the shape of a snowfall which lasted 40 hours and lowered the snow-level more than 3,000 feet. The whole country above 14,000 feet was laid under a continuous mantle of snow about a metre deep where it had not drifted."[1]

[1] D. W. Freshfield, *Tour of Kanchinjinga*, p. 5.

CHAPTER XV.

CAUSE OF CLIMATIC CONTRASTS.

Primary Climate Zonally Uniform—Cause of Seasons and Zones—Absence of Seasons in Primary Epoch—Cause of Climatic Variation in Coal Era—Seasons at the Dawn of Secondary Era—Zonal Differentiation in Permian Times—Seasons decidedly marked in Successive Zones—Permian Botanical Provinces Zonal—Zones in Later Epochs—Primary and Secondary Climates Compared—Cause of Contrast.

The changes in the Physical Geography of the earth's surface pointed out in the last chapter, accompanied as they were by the remarkable transformation from the mild and uniform atmosphere of the Coal period to the Arctic conditions required for the formation of the Permian glaciers, are no less remarkable than the facts brought to light by a comparison between the fauna and flora of the earlier epoch and those entombed in the later rocks. The character and distribution of these new beds also contribute valuable information, which indicate the cause of the changes which the earth experienced.

The climate of the Primary epoch was singularly uniform throughout the year; summer and winter were practically or entirely unknown. There were no seasonal changes. It was geographically uniform: there were no zones of varying temperature: no equatorial heat or Arctic cold.

Primary Climate Zonally Uniform.—"Up to the close of the coal period, every cause of the distinction of climatic zones and of botanical provinces seems to have been absent. This is attested by the marine species, as well as by the vegetation.[1] The universal character of the coal vegetation implies a nearly absolute equality in the distribution of heat and light over the whole globe."[2] "The specific identity of many of the brachiopods of the lower Carboniferous rocks, situated at enormous distances from one another, from the Arctic circle to the South of the Equator, is a strong proof of the general uniformity of temperature and marine conditions during the epoch."[3] This equability was characteristic of the whole of the Primary history.[4]

[1] David White, "The Paleozoic Floras," *Am. Journal Geol.*, vol. xvii., 1909, p. 336.

[2] A. de Lapparent, *Traité de Geologie*, 5th ed., 1906, p. 989.

[3] Sir R. I. Murchison, *Siluria*, 1867, p. 303.

[4] Bailey Willis, "Paleogeographic Maps: Middle Ordovician, and Silurian," in Bailey Willis and R. D. Salisbury's *Outlines of Geol. History*, 1910, p. 91.

The absence of zonal differentiation in the climate of the Primary ages is questioned by some geologists. It is believed that the ancient glacial deposits are sufficient to disprove this, and that an Arctic zone and consequent climatic gradation is required by them. It is to be remarked, however, that the glaciers of the present day, if all the other facts are ignored, would suggest a uniform climate, as there are glaciers in equatorial, temperate, as well as Arctic regions. No one would contend, however, that this was sufficient to disprove all the facts pointing to the contrary; and so in the Primary rocks the evidence so clearly indicates that zones were absent that the presence of glacial beds appears to be quite inadequate to controvert it. Moreover, the study of glacial phenomena tends to prove with more and more certainty that the accumulation of ice is related to altitude of the land rather than latitude. All that can be said with certainty with regard to these ancient glaciers is that they prove elevated regions, and not necessarily Arctic zones. It is, moreover, by no means certain that there are any glacial deposits between the base of the Cambrian and the close of the Carboniferous which leaves the whole of the Primary system free from this objection.

Cause of Seasons and Zones.—The differentiation of the climate of the earth into Tropical, Temperate, and Frigid zones, each of which graduate one into the other, is due to the variation of the angle at which the rays of the sun strike the earth and are refracted from it. At the Equator, where the angle is acute, the heat is intense. Towards the Poles the angle becomes greater, and consequently the temperature lower.

The yearly change of seasons is intimately related to this. If the Polar axis of the earth were at right angles to its plane of rotation round the sun, the zonal differentiation would remain, but there would be no variation from season to season. Since the axis is not vertical, but at an angle to the plane of rotation, the Poles incline alternately towards and then away from the sun during one yearly revolution. In this way, in Northern latitudes during the winter, the Arctic zone creeps southwards towards the Equator, while in the summer the tropical zone extends northward. The heat is felt far into Arctic regions, and the average temperature throughout the northern hemisphere is raised. For the same reason, while it is summer in northern latitudes it is winter in southern. The sun and the Arctic glaciers are thus both controlling factors in the maintenance of the climate in its present condition.

Absence of Seasons in Primary Epoch.—Plant life records with unfailing precision the influences of the solar light and heat and Arctic cold experienced by it. Climbing plants entwine themselves round the stems of larger ones, as the growing shoot, in its sensitiveness to these influences, follows the sun's motion in the heavens, and is attracted by it. In Temperate regions, where the

seasons are very distinctly marked, the wood of trees always grows more quickly in the spring than in the autumn, and the variation in growth is recorded in the structure of the wood. Annual rings indicate the successive seasonal increase of tissue. A slab of wood cut from a Californian Big Tree is exhibited in the British Museum of Natural History, and has been marked with the principal historic events which took place during its growth, from A.D. 557 to 1881.

The majority of the trees of the Devonian [1] and Carboniferous forests in the Temperate zone reveal no evidence of seasonal change. The secondary wood of a *Calamite* does not exhibit any regular zones of growth comparable with the annual rings of our forest trees,[2] neither does the general uniformity in size of the secondary conducting elements of the *Lepidodendra* afford any indication of changing seasons.[3] "The absence of annual zones demonstrates in an undeniable manner that the climate of the coal period remained the same during all the year; there were no changing seasons." [4]

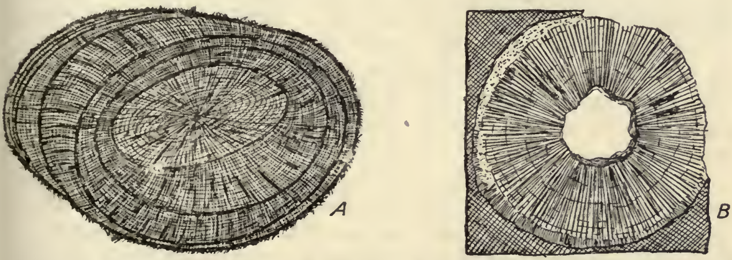


Fig. 28.—Transverse Sections of Carboniferous Woods to illustrate Growth.—A, Vascular axis of large root of Cryptogamous plant with eight zones of growth. B, Dadoxylon stem. Diameter four times natural size. (W. C. Williams, *Phil. Trans.*, 1874 and 1877.)

Although in a large majority of cases the structure of the woods reveals an absence of annual rings, a few instances are recorded of Carboniferous woods which show rings, although they are usually indistinct or irregular, and the illustrations in Fig. 28 are taken from enlarged transverse sections in order to show this.

Causes of Climatic Variation in Coal Era.—As the general opinion of undoubted authorities so strongly leans towards the conclusion already stated, it becomes necessary to inquire if there are other causes which would explain this structure, and whether there are

[1] David White, "The Upper Paleozoic Floras: their Succession and Range," in Bailey Willis and R. D. Salisbury's *Outlines of Geol. History*, 1910, p. 143.

[2] A. C. Seward, *Fossil Plants*, vol. i., 1898, p. 313.

[3] *Ibid.*, vol. ii., p. 93. David White, "The Paleozoic Flora." *Am. Journ. Geol.*, vol. xvii., 1909, p. 338.

[4] P. Bertrand, "Les Phènomenes glaciaires de l'époque permo-carbonifière." *Soc. Geol. du Nord Annale*, vol. xxxviii., 1909, p. 122.

evidences of such causes being in operation during the period under discussion.

1. Annual rings in recent woods usually indicate the variation in rate of growth from season to season; the denser portion of the rings indicating Autumn and Winter additions. There are, however, other causes which are known to produce similar results. During periods of drought, as are frequently experienced in Senegal, growth is interrupted, and this gives rise to a second ring during the year.[1] Variation in the supply of moisture to the roots, which is the principal means of nutrition, is thus portrayed in the wood tissues.

2. The reaction of physical change upon climate during the progress of the Coal epoch, producing on the one hand desert conditions, and on the other heavy rains, and discussed in the last chapter, appears to have been very general over wide regions of the earth, but the conditions were such that local disturbances may have produced similar results during the growth of vegetation, so that a particular district may at one time have been low-lying and marshy, and at another elevated and well-drained. These movements were also the cause of changes of temperature.[2] So that the growth of tissues in the stems and branches of the coal flora was affected by both these circumstances, but the change in the rate of growth would be irregular, as in the instances illustrated.

The occasional instances of ringed growth are not, therefore, inconsistent with the absence of seasonal variation in climate in the modern sense. The zonal and seasonal changes now in operation are so intimately connected in one common cause, that the absence of climatic zones at any period would necessarily imply an absence of seasons. The climatic variation in the older epoch was thus of an entirely different character to what is now experienced.

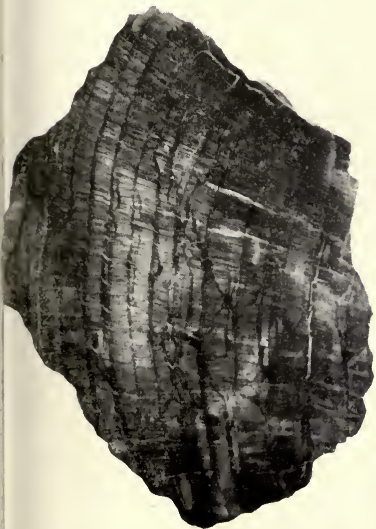
If, therefore, the present is the key to the past, we may, in reviewing the history of these deposits, conclude that the light and heat energy of the Sun had not been experienced upon the earth up to the close of the Primary epoch. Throughout the earlier periods the world had been illuminated from other sources, not different from those at present existing, but in a manner quite different to now, and this accounts for the other peculiarities noticed in the coal flora, such as the absence of flowers.

Seasons at the dawn of the Secondary Era.—Almost as soon as the next series of deposits is entered, there are marked evidences that the climatic conditions were entirely altered. Both the Permian and Liassic woods show that the annual growth was very decided at that time. This is shown in Plate vii., in which typical woods

[1] A. C. Seward, *Fossil Plants as Tests of Climate*, 1892, p. 80.
[2] David White, "The Upper Paleozoic Floras," in Bailey Willis and R. D. Salisbury's *Outlines Geol. Hist.*, 1910, p. 145.

ig. 1.—Lepidodendron from the Calciferous Sandstone, Berwickshire. × $\frac{1}{1}$.

Fig. 2.—Cycadoxylon from the Lower Coal Measures near Oldham. × $\frac{5}{8}$.



ig. 3.—Dadoxylon from Permo-Carboniferous, Australia. × $\frac{4}{5}$.

Fig 4.—Araucarioxylon from the Upper Lias, Whitby. × $\frac{12}{13}$.

Transverse Sections of Fossil Woods.

Scale linear.

from the Carboniferous and early Secondary rocks are compared. The faint but irregular rings in the older sections are in marked contrast to the distinct and regular ones in the later. The first decided indications of annual seasonal growth of wood fibre in the geological record are thus preserved in the Permian rocks. The Liassic woods are perhaps more nearly comparable with recent ones, and suggest that the revolution was slow in coming into operation, and that the full effects were not felt until Secondary times had well advanced.

No sooner was the glacial phase over than the new vegetation, with the regular seasonal character of the climate impressed upon it, took possession of the land. The annual rings, which are absent in the Upper Carboniferous, are conspicuously developed in fossil trees, preserved in strata, overlying the glacial conglomerates of New South Wales, Queensland, and Brazil.[1]

The footprints of winter also left impressions in the lignites of the Cromarty Lias. "In a specimen now before me," says Hugh Miller, "the alternation of summer heat and winter cold are as distinctly marked in the annual rings, as in the pines or larches of our present forests, whereas in the earlier lignites, contemporaneous with the ichthyolites of the ancient type, either no annual rings appear, or the markings, if present, are both faint and infrequent."[2]

The *Araucaria*, or Pines of the Liassic age, are distinct from the Conifers of the Primary forests. The wood is homogeneous and fibrous, and the concentric rings and medullary rays are usually more regular in well-preserved specimens. The annual growth is clearly defined in the Autumn and Spring wood, and the rings are clearly marked and narrow. Jet is composed of this wood in an altered state. A specimen in the Whitby Museum shows an inner core of "sandstone showing in places distinct indications of concentric rings, traversed here and there by crystalline lines which mark the position of the medullary rays."[3] In this case the inner portion has become petrified, the outer only being converted into jet.

It is important to notice that the change in the character of the vegetation during the Permian transition is very marked in the temperate zone. In the Tropics, Cryptogamous species still thrive, where the seasons are not so clearly defined. It is in the temperate zone, where the seasonal change is now most marked, that the fibrous wood with the annual rings appeared in the Trias, and where there were no signs of seasons in the Coal epoch. The Cryptogams did not die out altogether, but were subsequently restricted to the Tropics.

[1] David White, *Am. Journ. Geol.*, 1907, p. 622.
[2] Hugh Miller, *Old Red Sandstone*, p. 141.
[3] A. C. Seward, *The Jurassic Flora*, 1900, p. 68.

Zonal Differentiation in Permian Times.—The dawn of the geographical differentiation of the climate of the world is as clearly distinguished as the seasonal differentiation. A careful consideration of the distribution and extension of the Permian rocks, together with the geographical range of the flora which succeeded the glacial era, is quite sufficient to prove that this epoch saw the newer conditions established, which have continued down to the present time.

In the first place, the more important accumulations of these conglomerates occupy an approximately zonal belt of latitude, stretching round the northern hemisphere in an eastern and western direction. M. Lapparent has prepared a map of the globe with the superficial extension of the Permian rocks, which shows this very clearly.[1] Sir R. I. Murchison also pointed out that the European rocks of this age border the 50th parallel, and are mostly within it. When it is considered that the relative level of the land is the most important factor in the production of glaciers, and that they are usually confined to the mountainous heights, it is remarkable that the zonal distribution of the Permian should be so decidedly zonal as it is.

Where the Permian conglomerates proper are developed in Europe, they are distinctly a northern deposit, and have usually been derived from sources between the zone in which they lie and more Arctic regions. In some parts of the world nearer the Equator there is less evidence of glacial abrasion in rocks of the same age, if it does not entirely disappear. The basal conglomerate in Nyassaland at about 10° from the Equator is a torrential deposit rather than directly glacial, as the more southern ones are.[2] The pebbles of which it is composed are water-rolled and not striated. Local glaciers existed at high altitudes near the Equator, as the striated rocks beneath the tillite indicate a southward movement of the ice. Crossing the Atlantic, the Texan Permian consists of ordinary aqueous sediments, such as sandstone, clay, and limestone.[3]

If, therefore, the main ice sheet extended into equatorial latitudes, it was more rapidly melted than in more temperate regions, in which case zonal distinction was already marked. If it did not extend generally so far as that, it did exist in colder latitudes, and the ice was generally arranged according to the zones, and probably increased in depth towards the Poles.

The evidence borne by the distribution of these rocks suggest a Frigid zone covered with a great depth of ice, a temperate zone of morainic or fluvio-glacial accumulation, and a Tropical zone of sedimentation where water was deep enough. This indicates that

[1] A. de Lapparent, *Traité de Geologie*, 5th ed., 1906, p. 1018.

[2] A. R. Andrew and T. E. G. Bailey, "The Geol. of Nyassaland." *Quart. Journ. Geol. Soc.*, vol. lxvi., 1910, p. 192.

[3] W. B. Scott, *Introduction to Geol.*, 1897, p. 430.

the ice was massive in Northern regions, and thinned out towards the Equator, where it was absent, or, if present, confined to high altitudes; and other facts point to a similar conclusion.

It was the enormous pressure of the ice, together with the seasonal changes, producing the intermittent motion of the ice, that accounts for the accumulation of the Permian tillite. The degree of rock abrasion varied with the depth of the ice, and the strength of the fluvio-glacial currents, and was greater as it receded further from the Equator, since the more Northern and more Southern zones of the respective hemispheres were being ground down for longer periods. The detrital rocks formed in this way may be expected to thin out in the same way as the ice had done, and this is seen to be the case on both sides of the Equator. The Permian conglomerates of the Grand Cañon Basin of North America thin out south-eastwards. In England, east and west of the Pennine chain, they appear only as a fringe, while to the south they stretch out into wide plains and thin out southwards.[1]

This feature is even more pronounced in Africa, where the Dwyka is thicker in the south than in the North,[2] and in Australia, where, in the district where the boulder beds are typically represented, the outcrops gradually disappear in a northward direction. The reason for this is that the beds themselves thin out towards the north, or that they dip in that direction.[3] Both of these phenomena are characteristic of deposits laid down by melting glaciers, so that in this respect there is a similarity between them and those in other parts of the world. The glaciation of the pavement beneath the beds also agreed with this. The directions of the scorings in all the States of the Commonwealth also indicate a motion of the ice in general from south to north.[4] The striated pavement under the Karoo bed is grooved and furrowed in a north and south direction,[5] and agrees with the Australian and with the thinning out of the moraines northwards; but, at the same time, there is evidence of local dispersion of glaciers, and they radiated in the south, south-east, and south-west directions.[6] This probably took place after the general retreat of the *mer-de-glace* from the district, which left highland centres near the Equator still clothed with ice.

Throughout the early Secondary period, the sea encroached more and more upon the Continent of Europe,[7] and the invasion

[1] J. A. Jukes Browne, *Building of Brit. Isles*, 3rd ed., 1911, p. 204.

[2] A. W. Rogers, *Intr. to Geol. of Cape Colony*, 1905, p. 400.

[3] R. L. Jack and R. Etheridge, *The Geology and Palæontology of Queensland and New Guinea*, 1892, p. 83.

[4] G. F. Wright, *Ice Age in North America*, 2nd ed., 1911, p. 492.

[5] F. H. Hatch and G. S. Corstorphine, *Geol. of South Africa*, 1909, p. 234.

[6] W. M. Davis, "Observations in South Africa." *Bull. Geol. Soc. Am.*, vol. xvii., 1906, p. 413.

[7] A. de Lapparent, *Traité de Geologie*, 5th ed., 1906, p. 1011.

proceeded from south to north.[1] A similar transgression was in progress in China at the same time.[2] They were apparently due to the melting of the glaciers, and followed the direction of the retreating ice sheath.

Seasons Decidedly Marked in Successive Zones.—A most interesting and important confirmation of these conclusions arises from the following facts:—In an ascending succession of rocks, the Upper Carboniferous in the Southern hemisphere and Brazil is followed by a glacial conglomerate. The flora of the succeeding beds in Brazil prove a moderation of the climate, at which time trees with annual rings make their appearance. And then after a relatively short geological period, the equable conditions returned and permitted the growth of hardier lycopods without annual rings.[3] This proves that in this locality the nearness of the glaciers to the Equator produced conditions of climate similar to the present temperate zone, and that the ice was slowly dispersed. The temperate climate receded from the Equator with the retreating ice, and a truly equatorial condition with less marked seasonal changes, analogous to the present, ensued there.

It is suggestive that the decided seasonal changes left their impression upon the Equatorial Permian in Brazil, the Temperate Lias in Great Britain, and in the more Arctic Jurassic of Spitzbergen.[4] The geographical advance of the climatic changes towards the Poles is fully in accord with the geological age of the rock in which the evidence is preserved.

The ice evidently existed down to low latitudes, and was probably the cause of the restriction of faunal migration in the Permian age. When the glaciers receded northward, the inter-communication between Europe and America, which had previously been quite free in the Carboniferous before the glaciers were formed, was again opened up in the Trias.[5]

Permian Botanical Provinces Zonal.—The widespread distribution of the coal flora, which extended far into Polar regions with no distinct botanical provinces, was quite changed in the succeeding period. The close of the Upper Coal measures epoch and the dawn of the Permian witnessed the transition from the cosmopolitan to a provincial distribution of the world's flora. The botanical provinces which were now established indicate that climatic zones were also instituted, and were a controlling factor in the migration of the new flora. This is shown by the accom-

[1] A. de Lapparent, *loc. cit.*, p. 1193.
[2] Bailey Willis, *Research in China*, vol. ii., 1907, pp. 96-100.
[3] David White, "Permo-Carboniferous Climatic Changes in South America." *Am. Journ. Geol.*, vol. xv., 1907, p. 623.
[4] F. W. Knowlton, "Succession and Range of Mesozoic and Tertiary Floras," in Bailey Willis and R. D. Salisbury's *Outlines of Geol. Hist.*, 1910, p. 205.
[5] S. W. Williston, "The Faunal Range of the Early Vertebrates." *Ibid.*, p. 169.

panying illustration, in which the zones occupied by the northern and southern types are defined.

The importance of this does not lie in the distinction between the floras of the Permian and Carboniferous, or between the two Permian types, but in their relative distribution. There is no marked difference between the earlier and later except that a new class made its appearance in the Permian, and is known as the *Glossopteris* flora. The interest lies in the fact that the universal temperate flora of the Coal epoch was confined more or less decidedly to the Temperate zone in the Permian. It was thus restricted to those regions where the climate more closely approached its accustomed temperature. The new type, which now made its appearance, was characteristic of the South temperate zone, where glaciation had been excessive, and it is noticeable that this type migrated into the north temperate regions in that particular locality where

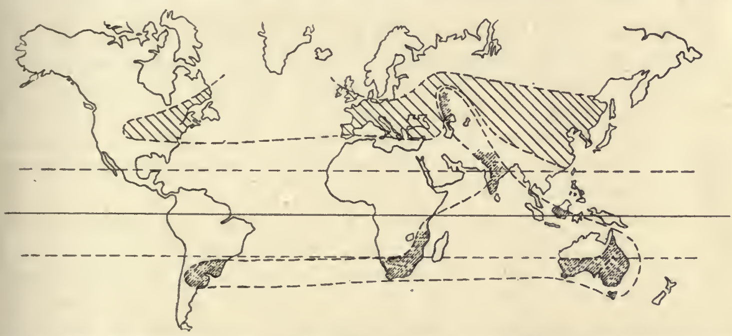


Fig. 29.—Map to illustrate the Zonal Distribution of the Northern and Southern Types of Permo-Carboniferous Floras. (Newell Arber.)

glaciation had also been severe.[1] The Permian botanical provinces were thus defined or modified by the new climatic differentiation, and also by the presence of local glaciers at high altitudes. The irregularity of the zonal provinces was, therefore, due to the same operating causes which produce similar irregularities in modern climatic zones. For the purpose of the present argument, there is no need to distinguish between the northern and southern types, and if this distinction was neglected the zonal distribution would be even more definite.

Zones in Later Epochs.—This accumulation of facts seems to prove that the divisional zones of the world's climate, which were absent at the close of the Primary era, were already distinctly defined as soon as the Secondary epoch commenced. The Jurassic rocks, which come next to the Trias, appear to present three different facies, each occupying a wide belt passing round the earth in the

[1] E. A. Newell Arber, *Fossil Plants of the Glossopteris Flora*, 1905, pp. xxv-xxviii.

direction of parallels of latitude, both north and south of the Equator in Europe [1] and America.[2] "We must, in fact, conclude that the climatic zones had been established in our earth in Jurassic times." The palæontological evidence proves that this was the case in Cretaceous times,[3] while at the close of the Secondary epoch the Eocene forests show that the zonal differentiation was more marked than it is at present. The remains of forests, which grew far into the Arctic circle at that time, consist of temperate species, the types which grew in what is now the temperate zone are Tropical, from which it is to be inferred that the Tropical zone experienced ultra-tropical conditions.

Primary and Secondary Climates Compared.—The evidence of the Secondary rocks shows that the ice was dispersed by the sun, zone by zone, from the subtropical, through the temperate, and probably at a continually decreasing rate into Arctic regions, until not a vestige remained.

Whereas in the coal period there was an almost absolute equality in the distribution of heat and light over the whole globe, the early Secondary epoch saw the slow arrival of the more unequal distribution of heat and light.[4] The uniformity of the Primary gave way to the diversity of the Secondary. The cause of the alternation of seasons and zonal differentiation, which was wanting in the older period appeared in the newer.

The fauna, flora, lithological character and distribution of the rocks of the Primary system show that throughout the long ages of their history there was a marked absence of the phenomena which are now attributed to the sun's action; whereas as soon as the Secondary system is entered, the more varied conditions were already being experienced. Added to the negative evidence of the coal era, which closed the Primary epoch, we have the positive of the early Secondary. The phenomena which are lacking in the closing scenes of the earlier epoch, and which we should expect to find there, if the sun had been exerting its influence upon the earth, present themselves as soon as the threshold of the later one was passed.

Up to the close of the Primary epoch, therefore, the whole of the Solar Planetary System received its light from an exterior source, or sources other than the sun. The process of earth building was carried on by organisms, which derived the light energy from other suns in the vastness of space, but towards the termination of that epoch the conditions were changed, and the sun became the principal source of the illumination of the system.

[1] E. F. H. Kayser, *Text-book of Comp. Geol.*, tr. by P. Lake, 1893, p. 271.

[2] T. W. Stanton, "Succession and Distribution of Late Mesozoic Invertebrate Faunas in North America," in Bailey Willis and R. D. Salisbury's *Outlines of Geol. Hist.*, 1910, p. 185.

[3] E. F. H. Kayser, *loc. cit.*, p. 283.

[4] A. de Lapparent, *Traité de Geologie*, 5th ed., 1906, p. 1027.

Cause of Contrast.—This is accounted for by the difference in the progress of events in the respective evolutions of the Sun and Earth which was provided for in the introductory scheme. The Sun had advanced many stages in the progress of its evolution, and had probably experienced many periods of igneous activity similar to those which were repeated in the earth's history. Upon the assumption that the same processes have been in operation during the sun's evolution, it is suggested that an unusually strong outburst of volcanic energy welled up from the deep interior and involved the whole of the solar crust. The oceans within which it had been built up were then unable to check the advance of the internal fires, and were entirely dispersed by them, and the solar crust was wholly involved. The Sun gradually assumed the igneous aspect. The rocks passed from the solid to the igneous state, and commenced to dispense the light- and heat-energy which for long ages had been stored up within them.

Hitherto the Earth and the Solar system had received light from other Solar systems in the heavens, but now the Sun became the centre of illumination.

CHAPTER XVI.

CAUSE OF GLACIAL EPISODE.

Croll's Theory of Climatic Changes—Necessary Conditions required for the Formation of Glaciers—Conditions fulfilled in different Ice Ages—Opinion now favours Uplifting of Mountain Masses as Cause of Ice Ages—Due to Excessive Phase of Earlier Earth Movements—Astronomical Forces and Terrestrial Deformation—Magmatic Fusion and Astronomical Forces — Uplift followed by Subsidence — Manner of Accumulation of Permian Glaciers—Gradual Melting of Ice and Glaciation.

It is not intended to review the many theories that have been advanced to explain the cause of the refrigeration of the earth's surface. A number of suggestions have been made, both from the astronomical and geological standpoints. They have usually been applied to "the Great Ice Age," which took place long after the close of the Secondary epoch, but Mr. Croll, who noticed the recurrence of glacial conditions at different geological stages, attempted to show that the repetition of climatic cycles was due to the variation which takes place from time to time in the earth's movements.

Croll's Theory of Climatic Changes.—The earth traces an elliptic path in its yearly journey round the sun, which is one of the foci of the figure. It is convenient to speak of this motion as circular, with the sun slightly removed from the centre, so that the earth rotates eccentrically around it. At the same time, the inclination of the polar axis to the plane of rotation causes an angularity or obliquity between the earth's plane of rotation and its plane of revolution. Both the eccentricity of the orbit and the obliquity of the ecliptic, as it is termed, have an important influence upon the climate of the earth. As each of these varies from time to time, it is thought that when the time of maximum obliquity coincides with the time of maximum eccentricity, the change of seasons may be sufficiently pronounced to produce a marked extension of the polar ice.[1]

This was at one time the more generally accepted theory of the cause of glacial epochs, but at the same time leaves much unexplained. The mere extension southwards of the limits of the Frigid zone would not necessarily increase the area covered by the Arctic and Antarctic ice caps. "It is not cold which has given birth to glacial regimens." Cold in itself is impotent to nourish glaciers.[2] An excessively cold atmosphere is often an exceptionally dry one. The chilly winter of the Siberian plains generates dry and piercing

[1] James Croll, *Climate and Time*, 1885, p. 402.

[2] A. de Lapparent, *Traité de Geologie*, 5th ed., 1906, p. 1768.

winds, which do not carry sufficient moisture for forming glaciers, although the temperature may be exceedingly low.

Necessary Conditions required for the Formation of Glaciers.—The present distribution of glaciers proves that they depend as much upon the variation in the height of the earth's surface as upon any relation to the Frigid zone. There are glaciers upon Mount Kenia within a few degrees of the Equator. The Alpine glaciers are an isolated group, and in no way connected with Polar ice. Also, the wide stretching plains of Siberia harbour no glaciers, whereas the higher peaks of the Himalayas of India, far to the south in the Temperate zone, are swathed in ice at all seasons of the year.

This is also true of the glaciers of the "Great Ice Age," which were confined to particular localities. They covered all the heights of Western Europe, Scandinavia, Finland, the greater part of the British Isles, and parts of France and Switzerland. In similar latitudes in Siberia there is no evidence of glaciation.

At the same time, although glaciers are generally located in the highest regions of the earth, altitude alone does not account for their accumulation, so that neither cold alone nor altitude alone is sufficient to explain their formation. "It is the combination of a great atmospheric humidity with the uprising of mountainous centres of condensation which produces them. The mass of a range is as important as its profile." [1]

Conditions fulfilled in different Ice Ages.—These conditions were fulfilled both at the close of the Carboniferous period and at the time of the Great Ice Age. The atmosphere of the former period was at times unusually humid, while an order of dry and burning seasons alternating with seasons rainy and temperate was established before the dawn of the latter.[2] The hot and dry atmosphere had absorbed large volumes of moisture from the seas, so that at each period the air was rich with vapour before the advent of glacial conditions, and at each period the earth's surface was upraised. "The glaciers freely appeared at the moment when the Alps and so many other chains had just acquired their principal outline," which is also true of the Permian uplift. The previously humid atmosphere condensed upon the uprising mountains.

It is a striking fact that the Arctic and Antarctic ice exists where the present rainfall is least, and it is proved that before the Pliocene epoch there was no ice in Arctic regions, so that the Poles owe their ice-bound conditions to a corresponding uplift there. Our climate is now largely controlled by the glacial conditions at the Poles, instead of the glaciers being due, as Mr. Croll supposed, to the changes of climate.

Opinion now favours Uplifting of Mountain Masses as Cause of Ice Ages.—The causes which have produced the physical geography

[1] A. de Lapparent, *Traité de Geologie*, 5th ed., 1906, p. 1748.
[2] A. de Lapparent, *ibid.*, p. 1483.

of the earth are, it is now generally believed, the cause of glacial accumulation, but after the ice is formed the proportions and distribution of glaciers are modified by solar heat. The Alpine glaciers are always upon the north side of the mountains [1] away from the solar influences, and those of the Great Ice Age were especially so. In former ages they extended over much greater areas than now, but are now restricted to more limited regions by solar radiation.

Mr. Wallace has shown that there is nothing contrary to geological reasoning in the supposition that the uplifting of mountains has played an important part in the case, since all glaciers are found in the highest regions of the earth, and that " high land in an area of great precipitation is the necessary condition of glaciation." [2] Mr. James Park, of the New Zealand Geological Survey, now in progress, has observed that the severe glacial erosion, effected during the former extension of the glaciers there, immediately followed the uplift. He says, " the relationship between elevation and ice invasion and subsidence with recession is too marked to be lightly passed over." The respective earth movements may not be the sole cause of these climatic variations, " but that they were the dominating factors, seems to admit of little doubt." [3] The former extension of the glaciers of Mount Kenia in the Equatorial regions of Africa has been attributed to the uplifting of the district by those who have studied them on the spot.[4]

Two contributors to the symposium upon outlines of geological history in America strongly urged the claim that the direct influence of elevation of land upon climate is a probable cause of glaciation. The probability was pointed out that a radical climatic change attended the elevation at an earlier period of the Carboniferous, and that the maximum variation of climate was presumably marked by the climax of the uplift,[5] and that students of geology are looking with much hope towards the hypothesis that increased altitude of land is the cause of cold climate.[6] Since the earlier editions of his work upon North American glaciology, Prof. Wright has given increased attention to this subject, and is now strongly of the opinion that elevation of the land is the prime cause of ice accumulation, and thus supports Mr. Warren Upham's earlier contention. The almost universal occurrence of the Permian glacial beds severely taxes the older theories, and " if a former elevation be not admitted

[1] E. F. H. Kayser, *Text-book of Comp. Geol.*, 1893, p. 378.

[2] A. W. Wallace, *Island Life*, 1892, p. 136.

[3] James Park, " Geol. of Queenstown Subdivision." *Geol. Sur. New Zealand Bull.*, vol. vii., 1909, p. 42.

[4] Dr. J. W. Gregory, " The Glacial Geol. of Mount Kenya." *Quart. Journ. Geol. Sur.*, vol. l., 1894, p. 530.

[5] David White, " The Upper Paleozoic Floras," in Bailey Willis and R. D. Salisbury's *Outlines Geol. Hist.*, 1910, p. 145.

[6] R. D. Salisbury, " Physical Geog. of the Pleistocene, etc.," in *ibid.*, p. 269.

for the Indian glaciated district, we may justly ask, what else can have produced glacial phenomena so near the Equator?"[1]

It has been estimated that "the reduction of temperature necessary for bringing about a Glacial epoch would require an elevation of 6,000 feet in the case of England, and not much less for the Alps," which, compared with the diameter of the world, is but a minor undulation.

The events connected with the more recent glaciation in the Great Ice Age, as we shall see, followed one another in the same order as those of the Permian: denudation followed the elevation. It is, therefore, reasonable to conclude that the uplift which preceded the Permian glacial epoch was responsible for the severity of the climate which produced the ice.

Due to Excessive Phase of Earlier Earth Movements.—The upward movements were spread over long periods, so that between the humid and temperate climate of the coal epoch, and the final and severe glacial phase an intermediate period of aqueous precipitation ensued which would account for the current bedding and rolling of pebbles in some parts in the Permian.

The glacial episode of Permian age was consequently due to an excessive phase of the earth movements, which for a long period had been causing aqueous precipitation at repeated intervals during Carboniferous times. The glacial accumulation was not universal, but was confined to the greater altitudes and more Polar regions. It was preceded by aqueous condensation and erosion, and succeeded by fluvio-glacial denudation as the ice melted. The uplifting proceeded by successive stages, so that before altitudes sufficient for the accumulation of ice were reached, ordinary sandstone and shale were deposited by aqueous precipitation, as in the coal measures. There are also conglomerates of Talchir age, containing pebbles which are supposed to have been first rounded by water and afterwards carried by ice, as they are imbedded in the finest silt.[2] The overlying sands are clearly current-bedded, and indicate the presence of the running water after the glaciation.

Astronomical Forces and Terrestrial Deformation.—If the uplifting of the continental areas of the earth's crust, which took place at the close of the Carboniferous epoch, was responsible for, or directly connected with, the universal glaciation which followed (and we may justly conclude that it was), we have still to seek a cause for the elevation of the earth's surface to a sufficient extent to bring about the refrigeration of the atmosphere, either locally or universally.

Lord Kelvin has said that "were the crust of the earth of continuous steel, and 500 kilometres thick (that is, 350 miles), it would

[1] Dr. N. O. Holst, *Glacial Periods and Oscillation of Land*, tr. by Dr. F. A. Bather, 1901, p. 210.

[2] R. D. Oldham, *Manual Geol. of India*, 1893, p. 158.

yield very nearly as much as if it were india-rubber to the deforming influences of centrifugal force and of the sun's and moon's attractions." Some physicists have supposed that the earth is practically solid, on account of its rigid resistance to these forces. It can scarcely be conceived to be hollow, since it retains its shape under their influence. "In order that the astronomical motions may be performed, as we know they are, and that the surface may not yield to such forces, more than we know it does, the portions of the earth which are outside such a sheet (of molten matter), if it exists, must be much more rigid than we can reasonably conceive them to be."[1]

The tides of the ocean are the effects of the continued operation of those forces, and one of the clues to the solution of the problem. The effects of the gravitation of the sun and moon are distinctly felt upon the surface of the sea. They draw the water towards themselves, and cause the oceans to assume an egg-shaped form, the longer axis of which is along the direct line pointing to the attracting body. The tide raised by the moon in this way is about 5 feet in mid-ocean, that due to the sun about 2 feet. When the sun and moon are in affinity and acting in unison, the Spring tide is about 7 feet. When they are in opposition and acting against one another, the Neap tide is only about one-half of the Spring tide.

The crust of the earth is believed to rise and fall under the influence of the same forces. It has been estimated that the Spring tide in the solid portions amounts to twenty inches, and the Neap tide to about eight. These undulations are exceedingly slight and trifling compared with what is required to bring about a glacial epoch, but small as they are, they are the present effects of forces which physicists affirm are adequate to the task of producing far greater results.

Magmatic Fusion and Astronomical Forces.—The activity of the igneous magma, so evident in the coal epoch, reached a climax at the close of the period. The foundations of the earth's crust were undermined and rendered responsive to the forces we have just described. The forces of Solar and Lunar attraction, and those set up in the rocks by the revolution and rotation of the earth, combined with the volcanic energy far beneath to produce a general disturbance and upheaval of the crust. The central uplifting force, as in the case of the formation of the Rico Dome,[2] endeavoured to release itself, and, acting in conjunction with the other forces, effectively deformed the earth's envelope, and brought about the continental uplift of the Permo-Carboniferous times.

[1] Prof. A. E. H. Love, "The Yielding of the Earth to Disturbing Forces." *Proc. Roy. Soc.*, Series A., vol. lxxxii., 1909, p. 82.

[2] W. Cross and A. C. Spencer, "Geol. of Rico Mountains, Colorado." *U.S. Geol. Survey Ann. Rep.*, vol. xxi., p. 101.

In a previous chapter it was mentioned that pressure raises the melting point of solid rock, so that increase of pressure does not at first produce liquefaction, although the temperature may be high, but tends to retain the rocks deep down in the interior in a solid state. "If, however, the pressure were in some way relieved, they would become liquid." [1] The relief would lower the melting point, and liquefaction would be rapid on account of the high temperature. The forces which accompany the Solar and Terrestrial evolutions would thus, not only produce positive deformation, but also promote subcrustal fusion. In its normal state the crust successfully resists those forces, but as soon as its foundations were rendered insecure by becoming plastic or liquid, it would be peculiarly liable to feel the deforming influences. As soon as movement commenced, more material would probably melt, and the action and reaction would combine to produce a high degree of instability.

The part played by the exterior forces is seen in the character of the disturbances. The previous movements during the Coal period had been deep-seated and generally subterranean. The uplift at this time affected the deep interior and surface alike. Large areas of previously horizontal strata were upturned, so that the edges formed part of the new surface. Earlier disturbances probably produced squeezing and compression of the deep-seated rocks, but now the more superficial strata were upheaved, deformed, and faulted.

The problem of reconciling the observed results with the cause to which we wish to attribute them becomes simpler, if the relative extent of the rock contortion is taken into account. As Mr. de la Beche pointed out long ago, we may fall into grievous error by the neglect or "want of due attention to the relative proportions of the radius of the earth to the height of the mountains." The localities where the contortion of strata reached its maximum intensity are relatively few. If their number were multiplied, their relative distribution and magnitude would not be greater, if as great, as the wrinkles upon the skin of a somewhat shrivelled apple.

Uplift followed by Subsidence.—The uplift was no doubt of unequal extent in different parts of the world, and was followed by considerable local and general subsidence, both of which produced faults, lateral thrust, and overfolds. It is probable that the uplift brought the shell into a state of greater equilibrium between the terrestrial gravitation pulling the crust towards its own centre and the celestial, tending to draw it upwards in the opposite direction. A general settlement then followed the uplift and the disturbed portions of the crust, accommodating themselves to new positions, produced a rigid envelope which was again able to resist the outward forces still acting upon it.

[1] T. C. Chamberlain and R. D. Salisbury, *Geology*, vol. i., 1905-6, p. 598. J. N. Le Conte, *Elements of Geol.*, 5th ed., 1903, p. 227.

The folded and compressed state of the rocks in some localities is believed to be due to contraction or inward settlement of the crust, but although rocks have, in some instances, been powerfully compressed, "elsewhere they have undergone enormous tension."[1] Both of these phenomena are explained by the movements we have been considering, and it is reasonable to suppose that the extensions and compressions were local and balanced one another, while the general uplift was made possible by the molten and semi-plastic matter of the interior. Strata that had previously been contorted, as well as the newer deposits, were borne upwards, even if they may not have floated upon the molten magma as at a previous period.[2]

The upheaval was thus accompanied by magmatic invasion and extensive faulting of the strata, so that large numbers of dyke intrusions were formed. "Liquid matter being introduced among the fissures in all directions as the solid superficial portions separated to enable it to do so, the result being a state of comparative ease produced by the expansion having attained its limit."[3]

Manner of Accumulation of Permian Glaciers.—We have already seen that the uplifting of the earth's surface was followed by glacial accumulation, and that these two phenomena are cause and consequence, so that it is now only necessary to describe the manner in which the glaciers were produced.

It has been pointed out that a moisture-laden atmosphere is essential to the formation of glaciers, and this was exactly the condition of the atmosphere at the close of the Primary epoch immediately preceding the uplift. The excessive and repeated aqueous precipitation during the Coal measure period indicates that much moisture was continually being absorbed by the atmosphere under the uniform climatic conditions, and was again ready when the time for its use arrived.

The regional distortion of the earth's envelope, and the protrusion of mountainous masses, was effective in so far expanding the crust as to cool it to a more excessive degree than at any previous time. When, therefore, the refrigerated portions of the surface of the earth, as they were slowly and successively upraised, came into contact with the atmosphere, which was so richly charged with moisture, the conditions fulfilled all the requirements for the formation of great depths of snow upon them. The condensation of the moisture took the form of heavy snowstorms in higher and colder altitudes, or rains in lower and milder localities, and as soon as the warm rays of the sun, which now rose daily in the eastern horizon, proceeded to melt the snow, it became in this way consolidated into glacier ice or *nevé.*

[1] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1903, p. 415.

[2] F. D. Adams, "Bases of Pre-Cambrian Correlation," in Bailey Willis and R. D. Salisbury's *Outlines Geol. Hist.*, 1910, p. 14.

[3] H. T. de la Beche, *Research in Theoretical Geol.*, 1834, p. 159

The universality of the humid atmosphere before the uplift, together with the equally universal character of the continental elevation, as well as the widespread extension of the Permian deposits spoken of in the last chapter, combine to indicate that the glacial formation was very general at this time upon sea and land. Whereever the uplift was sufficient to cause excessive refrigeration, there the glaciers formed.

Gradual Melting of Ice and Glaciation.—The next stage in the progress of events was the melting of the glacial sheath. The dispersal of the icy envelope from off the uplifted continents was due to the motions of the earth, which exposed the surface to the sun's influence. It was necessarily a slow process, since in the neighbourhood of glaciers the temperature of the air is often much above the melting point of ice, yet little is liquefied on account of its latent properties.

The continental areas near the Equatorial regions were first freed. Then an ever-widening channel formed a girdle of water encircling the earth. Slowly, as the heat of the sun performed its task, the space between the northern and southern caps was increased in width, until eventually the ice was reduced into smaller and smaller compass within the Polar regions.

This particular ice enclosure was entirely melted away from the earth, and not a vestige remained. It was during the slow yielding of the ice mass to the influence of the heat of the sun that the Permian rocks were formed. The inequalities in the level of the land caused the ice to glide down the inclined planes into the valleys and hollows. The direction of its motion was generally towards the Equator, but was modified by local differences in level of the surfaces over which it moved.

During the long period of the break up of the ice sheath, the surfaces of the ice-bound continents were planed down, the inequalities were rendered less pronounced, the upturned edges of strata were levelled off, and mountain tops removed to form new deposits in the valleys. The softer strata were the first to suffer, until the indurated and metamorphosed rocks were reached, which in their turn were ground down, scratched, grooved, and polished. In this way the rocks worn off the ancient Primary land surface were laid down in the bed of the ocean, or in the valleys and low-lying plains, where they sometimes form the base of the Secondary System.

CHAPTER XVII.

THE JURASSIC SEAS.

Effects of Ice Age upon Internal Crust—Melting Ice and Fresh-water Lakes—Mode of Formation of Early Secondary Rocks—Shore Deposits derived from Older Rocks—Thinning-out from Source of Origin—Mechanical Derivation—Conflicting Features in Trias reconciled—Other Evidence of Current Action and Erosion—Retreat of Glaciers traced Geographically and Geologically—Early Secondary Period in Russia—America—Similar in India and China—Northern Latitudes—South Africa—Influence on Plant and Animal Life—Reptilian Fauna of Jurassic.

The close of the Primary epoch was particularly noteworthy as a time of continental upheaval. The close of the Secondary was equally marked in this respect, but the movements were different in character. The series of disturbances in the Coal epoch, which culminated in the uplift at the dawn of the Secondary era, may be compared with a similar series of crustal movements which commenced at the close of that epoch, and continuing through the Tertiary, also culminated in an era of mountain building. Igneous activity and mountain building were in each case followed by glacial accumulation and abrasion. The Secondary period, which we are now to consider, was preceded as well as followed by a sequence of these phenomena, which, although they did not present the same degree of intensity during their progress, yet followed precisely the same order. We have now under review a long, quiet, and undisturbed era, during which the Secondary rocks were laid down in shallow seas and beneath the wide expanses of ocean, which were gradually increased in volume by the melting of the Permian ice sheath throughout an exceedingly protracted geological era.

Effects of Ice Age upon Internal Crust.—The effect of the Permian ice age was as severely felt beneath the surface of the earth as it was upon the surface. The activity of the molten magma which continually asserted itself during early and mid-Primary times, and then broke out again at the close of that era, received a severe check with the dawn of glacial conditions. Volcanic outbursts were more or less continuous throughout the pre-Cambrian and Primary eras; in the Permian "they seem to have finally spluttered themselves out and become extinct. They did not reassert themselves for a long period."[1] "During the whole of the Secondary period the volcanic forces were dormant in the districts of the Western Highlands, yet that era was preceded as well as

[1] T. G. Bonney, *The Story of our Planet*, 1893, p. 408.

followed by an epoch of most intense and prolonged igneous activity."[1] "From the Permian to the early part of the Tertiary period there was a complete quiescence of volcanic activity, for in the Triassic, Jurassic, and Cretaceous formations no vestige of any contemporaneous igneous rock has been found."[2] This particularly refers to the British Secondary rocks, but is generally true of other parts of the world.

"The innumerable intrusive sheets and dykes of trap, generally basaltic, of Ireland are the kind of evidence upon which this conclusion is based. Some of them are distinctly of Tertiary age, while others are much older, probably of Carboniferous. The series of dykes which run across the whole of Scotland are considered by some geologists to be of Tertiary age, while the subaqueous lavas of Central Scotland and the intrusive masses of the Grampians were all formed at the latter part of the Primary epoch."[3]

Melting Ice and Fresh-water Lakes.—After the deformation of the earth's crust at the close of the Primary epoch, and when the ice sheet had retreated towards the Poles in the early Permian, the distribution of land and water was greatly modified. This period was perhaps, of all geological epochs, the one that has seen the sea to occupy the least place in Europe.[4] The melting of the ice from the continents to the North slowly filled up the depressions in Southern latitudes, and in time increased the water area. In England the seas were more widely extended in the Liassic than in the Triassic period. The advance continued, and was the early phase of a general invasion of the seas, which, as they increased in extent, covered more and more of the land, until in Cretaceous times they covered almost the whole of the pre-existing continents.

The fresh-water conditions of the late Primary era continued on into the early Secondary, as the lakes and seas in which these sediments were laid down were filled with water from the melting glaciers after they had retired from the Temperate zone. The Permian rocks were generally accumulated in great fresh-water lakes, of which the Karoo is one.[5] The similarity between the fresh-water fauna of the South African and the Russian basins has been pointed out.[5] The Permian beds of Russia were deposited in one great inland sea of brackish water occupying a vast depression in the earth's surface, which extended over enormous tracts of Asia.[6] The Godwana of India is a fresh-water accumulation reaching a total thickness of 13,000 feet.[7] In parts of Northern Russia and

[1] J. W. Judd, "The Secondary Rocks of Scotland." *Quart. Journ. Geol. Soc.*, vol. xxx., 1874, p. 222.

[2] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1905, p. 709.

[3] E. Hull, *The Physical Geol. and Geog. of Ireland*, 2nd ed., 1891, p. 175.

[4] A. de Lapparent, *Traité de Geologie*, 5th ed., 1906, p. 1011.

[5] A. W. Rogers, *Intr. to Geol. of Cape Colony*, 1905, pp. 198, 401.

[6] Sir R. I. Murchison, *The Geol. of Russia in Europe*, vol. i., 1845, p. 585.

[7] H. B. Medlicott and W. T. Blanford, *Manual Geol. of India*, p. xxviii., 1880.

in detached areas of France deposits of this age contain a rich fauna of fresh-water mollusca, and other fresh-water organic remains.[1] The Magnesian Limestone of England contains distinctly similar organisms, while "it is generally believed that the Keuper marls and New Red Sandstone of Britain were deposited in a great fresh-water or brackish-water lake."

Mode of Formation of Early Secondary Rocks.—The range of deposits we are now to consider were accumulated before the great transgression of the sea took place. They are now found lying in and around the Great Basins just referred to, and which held the water of the early Secondary seas. Some of the Permian seas were marine, and ordinary organic sediments were laid down in the deeper depressions. In Southern Europe, India, and other parts of the world limestone and marls with a marine fauna were in process of formation. In Texas and Kansas they are composed of sandstone, clays, and limestone, upwards of 5,000 feet in depth.[2] These deposits are somewhat widespread, and have been termed pelagic, to distinguish them from those formed in the shallower basins. At particular intervals the seas had access to and invaded the fresh-water lakes, so that marine and fresh-water fossils are

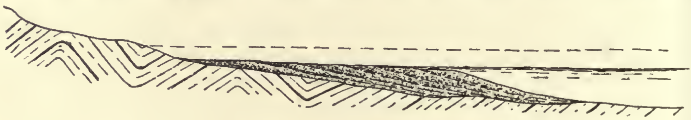


Fig. 30.—Oblique Stratification of River Silts in Lake.

interstratified or intermingled. The deposits of sand and silt laid down in the shallow seas are the more interesting, and will engage our attention.

In the first place, they reveal a similar mode of deposition. This is made clear by means of the sketches (Figs. 30 and 31). They illustrate the way in which running water deposits sand or mud that it brings down into a lake or the sea. The velocity of the current is checked as soon as it enters the larger volume of water, and it is no longer able to hold the heavier matter in suspension. The coarser particles fall close to the mouth of the stream, while the finer sediment is carried further out. In this way a series of layers is formed dipping and thinning out away from the mouth of the stream. The stratification is due to the variation in the velocity of the river.

The lower, thick line (Fig. 30) represents the normal water level. If the lake now becomes flooded to an unusual height, and remains so while deposit is formed all over the bottom, it will cover up the

[1] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1905, pp. 1074-7.
[2] W. B. Scott, *Introduction to Geol.*, 1897, p. 430.

earlier deposits, say, to the dotted line. The correspondence between this and a portion of the early Secondary system (Fig. 31) shows the way in which these rocks were formed.

The Permian and Jurassic rocks of England are true shore deposits formed largely by running water, which slowly filled up the basins to the south and east with silt. The water came from the glaciers, which during their early retirement towards the north produced copious streams, which emptied themselves into the sea along extended shore lines. The water carried loose earth and pebbles with it, and eroded the surface of the rocks over which it flowed, and deposited its burden upon the floor of the sea further south. Glacial till of Permian age remaining upon the land was also eroded, the angular fragments rounded into gravel, and spread out in layers again. The finer material found its way further out into the bed of the basin. The process went on continuously for enormous lengths of time, and the surface of the older upturned rocks were denuded and spread out in the form of new beds, even the newer deposits were eroded by the streams, and the silt was carried further on, to be laid down again.

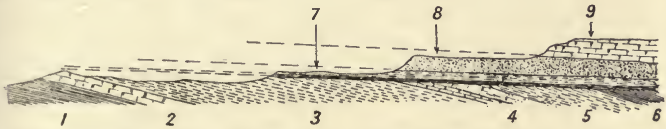


Fig. 31.—General Section, illustrating relation of Cretaceous and Jurassic rocks in Wiltshire.—1, 2, 3, Upper Jurassic. 4, 5, Portland and Purbeck. 6, Wealden. 7, Gault. 8, Greensand. 9, Chalk. (H. B. Woodward, *Geol. of Eng. and Wales.*)

Shore Deposits derived from Older Rocks.—The internal structure, distribution, and composition of the Permian, Triassic, and Jurassic rocks clearly corroborate the foregoing remarks. The English succession is developed along an old shore line, which extended from the Yorkshire to the Dorset coasts. The Trias and Jura are met with along the south coast beneath the newer rocks, and once formed the shore line of the ridge of ancient rock which occupied the English Channel at the dawn of the Secondary era, and has since been faulted down. It formed the southern limit of the English basin. A similar belt of Jurassic rocks "forms a rim to the Great Cretaceous and Tertiary basin of the North of France."[1] The English rocks are typical and have been exhaustively studied, and it is here that we are best able to follow the sequence of events.

There is a distinct relationship between the earliest Secondary rocks and the Primary ones from which they were derived. As in

[1] E. F. H. Kayser, *Text-book of Comp. Geol.*, 1893, p. 241.

the Permian of New Brunswick, so in other parts, the plant remains connect these beds with the upper Carboniferous rocks. The Magnesian Limestone sometimes contains fragmentary protozoa derived from the Primary rocks, and is made up of angular fragments of a pre-existing, very compact limestone, which, from the corals and other fossils found in it, proves to be Carboniferous limestone.[1] The Trias or New Red Sandstone is related to the Old Red, and consists of pebble beds containing, besides local material, abundant rolled quartz pebbles "probably derived from previous Old Red Sandstone conglomerates." The materials which compose these particular rocks, after being eroded from the disturbed Primary land surface, were carried by streams of running water and deposited in the shallow seas in such a manner that their origin is able to be traced from the similarity of its contents to neighbouring Primary rocks.

Thinning out from Source of Origin.—The attenuation of these rocks, as they are tracked further and further away from the old shore line, has already been alluded to. The Permian gradually disappears towards the south. "In the Midland counties the breccias attain a thickness of 450 feet, which is reduced to 200 feet as it trends southwards."[2] The respective members of the New Red Sandstone gradually expand in their range from south to north. From small beginnings in the south their successive development is accomplished northwards. The Trias of Great Britain is found in its greatest development in Lancashire and Cheshire. "It is attenuated in a south-eastern direction. Towards the north-west the series attains the maximum depth of 5,200 feet; they rapidly come down to a fifth or sixth of that thickness as they pass south-east." The Oolites also diminish in thickness in the same direction.[3] In the Eastern counties and around London, Primary rocks have been struck beneath the bottom of the Cretaceous strata at a depth of from 800 to 1,100 feet, wherever boreholes have been sunk. The early Secondary beds are missing there, which indicates that they die out altogether towards the South and East.

Mechanical Derivation.—The internal structure of these strata bears similar testimony. The Permian were evidently derived by glacial and fluvio-glacial erosion from, and spread out upon, the old Primary rocks. The Trias of the West of England was derived largely by mechanical means from the Mountain Limestone, upon which it sometimes rests. It occasionally contains boulders of granite and other rocks and pebbles of Devonian and Carboniferous limestone, Millstone grit, and Coal measure sandstone.[4] The upper Trias represents the debris of a large land area, the product of

[1] Sir R. I. Murchison, *Silurian System*, 1839, p. 47.
[2] Sir J. Prestwich, *Geology: Chem., Phys., and Strat.*, 1886-8, vol. ii., p. 132.
[3] J. A. Jukes Browne, *Building of Br. Isles*, 1911, pp. 269, 270.
[4] H. B. Woodward, *Geol. of Eng. and Wales*, 1887, p. 231.

great and powerful streams.[1] The main source of the supply of the sediments which form these deposits, probably lay towards the north-west and north, and possibly extended across the northern portion of the North Sea, connecting Scotland and Scandinavia. Current bedding was produced to a phenomenal degree in the south.

Conflicting Features of Trias reconciled.—The lower Trias seems to reveal a contrast so remarkable that it requires special mention, since the reconciliation of the apparent opposites strongly supports the argument for the cause which accounts for both. The Pebble beds suggest a season of unusually heavy rains, which produced floods of an almost cataclysmal character.[2] Boulders were swept out and carried great distances by swollen torrents, but, at the same time, the atmospheric conditions were so arid that deep beds of rock salt were precipitated, granite surfaces were preserved from the decay which they usually suffer when exposed to the elements,[3] and at the same time were eroded by long-continued sand-storms. The materials they carried now form beds of stone. These conflicting features can only be explained by the ice age. The aridity of the atmosphere was the result of the precipitation which produced the glaciers. A large proportion of the atmospheric moisture had been condensed upon the earth's surface, and was so largely abstracted that evaporation was excessive. Heavy rains were absent, so that the swollen torrents were not due to ordinary causes. The transportation of the pebbles to so great a distance was accomplished in successive stages by the rivers which flowed from the melting ice sheet.

Other Evidence of Current Action and Erosion.—The materials constituting the mass of the English Lias might well have been formed from materials carried in suspension in water, and derived from the waste of Primary limestone and shale, and not directly from organic remains.[4] It contains rolled fragments of crinoids and some grains which are clearly fragments of Carboniferous limestone. The finely laminated paper shales in the Lias, and the alternation of silts and sands, varying in colour, thickness, and texture, point to sheet floods charged with these materials held in suspension gently deploying over widely stretching sandy surfaces. The Great Oolite shows distinct false bedding, which is characteristic of deposits formed by torrential streams and rivers.[5] The Jurassic rocks of the West of England indicate deposition in clear still water free from sediment. When traced north-eastwards, they become, in mid England, more and more sandy, still further, inter-

[1] T. G. Bonney, *Story of our Planet*, 1902, p. 413.

[2, 3] A. J. Jukes Browne, *Building of Bt. Isles*, 1911, pp. 228-230.

[4] H. B. Woodward, "The Jurassic Rocks of Britain." *Mem. Geol. Sur. of U.K.*, vol. iii., 1893, pp. 28-32.

[5] James Geikie, *Structural and Field Geol.*, 1908, p. 116.

bedded bands due to estuarian conditions appear, until in Yorkshire the whole series consists of sandstones with alternating bands of carbonaceous matter, instead of coral limestone as in Gloucester. The upper and middle Oolites still preserve the beds of the rivers which brought down these sediments, and consist of alternations of marine, estuarian, and fresh-water strata.

The following illustration shows that the channels were cut during a period of inundation. The overlying beds were then laid down, after which another period of flooding and deposition took place.

The Kimmeridge clay and Portland stone, the deposition of which closed the Jurassic epoch, are widespread and deep deposits and "wholly marine." This refers to the fossils found in them. The sands in which the fossils are buried were derived by aqueous denudation from the older rocks by the torrents of water which came away from the glaciers, since the physical conditions of the Kimmeridge clays resemble those of the Lias.[1]

It is apparent that for long ages the glaciers slowly receded, while the seas increased in proportion as the ice melted. The oceans

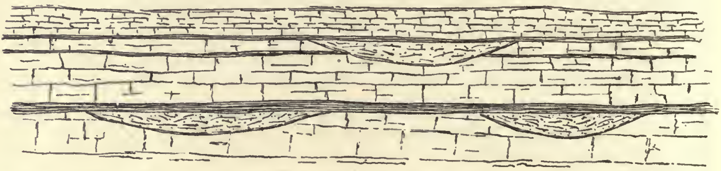


Fig. 32.—Old River Channels in Oolite Rocks of Malton. (C. S. Fox Strangways, *Mem. Geol. Sur. Eng. and Wales*, vol. liii.)

then became more saline as time went on, and at the same time received less and less sediment from the glacial torrents.

Retreat of Glaciers traced Geographically and Geologically.—The gradual passing of the fluvio-glacial conditions northward is revealed by the Kimmeridge clays. In the south they are wholly marine, and thicken southwards like an ordinary ocean deposit, while in Caithness quiet deposition of semi-estuarian beds was interrupted by occasional floods of the most violent character, rounded pebbles and trunks of trees torn from the banks of streams, are mingled in wild confusion with marine sands.[2] The agents of erosion which built up the Oolites in the south long before, continued on into Kimmeridge times in the far north, as the ice receded in that direction.

The same changes are witnessed in the geological sequence, if

[1] C. S. Fox Strangways, *The Jurassic Rocks of Britain*, 1892, vol. i., pp. 405-7.

[2] A. J. Jukes Browne, *Building of Bt. Isles*, 1911, p. 280.

the several formations in one locality are compared as when one formation is traced into an adjoining locality. The powerful currents of the Lower Oolites brought great quantities of sand and mud from the north, and filled up the depressions. They were so strong as to sweep back the sea in the Middle Oolites. There were frequent eruptions at short periods in the Upper Oolites, the Coral Rag was less liable to these incursions, and the indications of current action disappear in the Cornbash, while in the Oxford Clay period polyps were able to commence the building of coral beds in clear shallow water.[1]

Early Secondary Period in Russia.—Jurassic rocks of Russia were once widely extended formations. They are usually composed of sands, marls, and ferruginous sandstones, and not infrequently of beds of conglomerate, the rolled pebbles and stones of which have probably been derived from the disintegration of the Permian conglomerates which were re-arranged by mechanical submarine operations in the sea in which the Jurassic rocks were accumulated, or are similar to those at the base of the Oolite rock of England.[2]

America.—The Trias of New Brunswick, which covers the whole of Prince Edward's Island, was deposited by the action of running water, and contains pebbles mechanically derived from the Carboniferous rocks of the neighbourhood. The early Secondary strata of the Grand Cañon Basin of the western States bear striking resemblance to those of the English Basin. The Permian, Jurassic, and Triassic rocks are composed almost wholly of sand and clay, such as is being washed down by the existing rivers which flow through the gorges.[3] They, and especially the Trias, attenuate as they are followed in a south-eastern direction, and are littoral deposits formed of detrital matter worn off the ancient land surface beyond the shores of the basin to the north and west.[4]

The Triassic and Jurassic are conspicuous on the western border at the foot of the Rocky Mountains. They thin out rapidly eastwards, and contain a distinctly fresh-water fauna.[5] In Colorado and Utah, the Jurassic consists of a coarse-grained sandstone, from 800 to 1,000 feet thick, whose predominant characteristic is a remarkable development of false-bedded structure (see Plate VIII., Fig. 1). Sometimes it is amazingly cross-bedded, and consists of alternating fresh-water and marine beds.[6] The upper Jurassic of Alaska resembles the Kimmeridge Clay of Caithness. It was derived

[1] C. S. Fox Strangways, *loc. cit.*, pp. 395, 400.

[2] Sir R. I. Murchison, *Geol. of Russia and Ural*, 1845, p. 248.

[3, 4] C. E. Dutton, "Tert. Hist. of the Grand Cañon Dist." *U.S. Geol. Sur., Mono.* ii., 1882, pp. 48, 237.

[5] C. A. White, "The Relations of the Laramie Mollusca to the Eocene." *U.S. Geol. Sur. Bull.*, No. 34, 1886, p. 13.

[6] C. A. White, "The Fresh-water Invertebrates of the North Am. Jurassic." *U.S. Geol. Sur. Bull.*, No. 29, 1886, pp. 54-7.

from the destruction of the land, and reveals the effects of the contemporaneous erosion and deposition.[1]

Similar in India and China.—The rocks of the same age in India are characterised by the frequent alternation of coarse and fine beds. These shales and sandstones are frequently current-bedded, and oblique lamination, due to the deposition by currents, is common. The older beds were often locally worn and denuded, and coarse sands were then deposited upon them.[2] The Jurassic series of Cutch consist of alternating marine and fresh-water beds, which also contain the remains of land plants.[3] In Northern Afghanistan there is the same evidence of the local thinning out of these rocks to the south and west, and they consist of the usual sandstone, carbonaceous shales, grits, conglomerates, and thin seams of coal.[4]

These formations in China are of the continental type, consisting of red and yellow sandstones and conglomerates, composed of detritus from older rocks or sandstone and shales with beds of coal. The ancient underlying surface was swept clean by currents which flowed across it, possibly with variable velocity. These currents may have been checked or diverted, so that the terrigenous deposits were laid down on the scoured surface.[5] The prevailing rock is a firm, coarse-grained sandstone, with seams of conglomerate containing pebbles up to 12 inches in diameter. Cross-bedding inclined at angles of about 20° towards the west is very prominent in the sands.[6]

In Northern Latitudes.—During Triassic times, in the far north, fossiliferous rocks were laid down beneath the ice-bound seas. Towards the close of that epoch and the dawn of the Jurassic, the seas there received incursions of silt-laden currents from neighbouring land, and the immense perfectly rounded nodules of limestone, containing saurian remains, were deposited in the marine sediments either by those currents or by floating ice or by both agencies. The seas were afterwards closed to those currents, doubtless on account of more severe Arctic winters, during lower Jurassic times, and marine deposits were again laid down. The late Jurassic is marked by the return of littoral conditions, when typical sandstone and shales with coal beds were accumulated,[7] similar to those in other parts of the world in more temperate latitudes. The North Polar ice sheet was thus very irregular in its southern limit at this

[1] T. W. Stanton and G. C. Martin, "Mesozoic Section on Cook Inlet and Alaska Peninsula." *Bull. Geol. Soc. Am.*, vol. xvi., 1905, p. 403.

[2, 3] R. D. Oldham, *Manual Geol. of India*, 1893, pp. 150, 216.

[4] H. H. Hayden, "Geol. of Northern Afghanistan." *Geol. Sur. India*, vol. xxxix., 1911, p. 30.

[5] Bailey Willis, *Research in China*, vol. i., part 1, 1907, p. 82.

[6] Bailey Willis, *Research in China*, vol. i., part 1, 1907, p. 316.

[7] Prof. A. E. Nordenskiold, "Geol. of Spitzbergen." *Geol. Mag.*, 1876, pp. 119, 131.

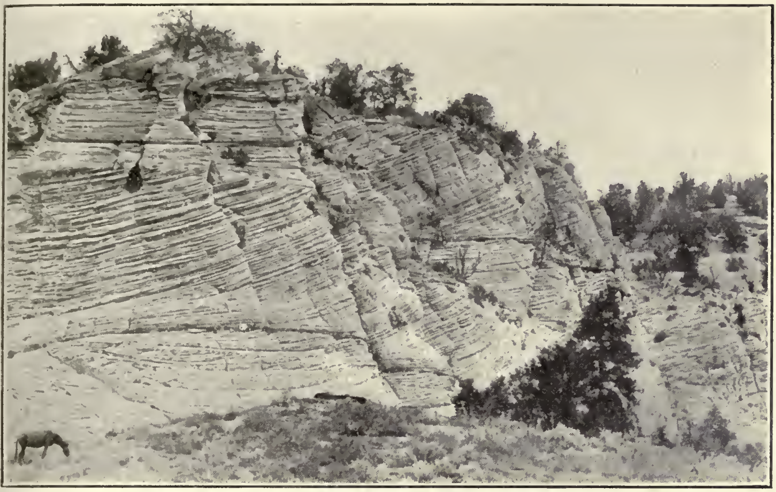


Fig. 1.—Current-bedded Jurassic Sandstone. Utah.

United States Geological Survey Photograph.

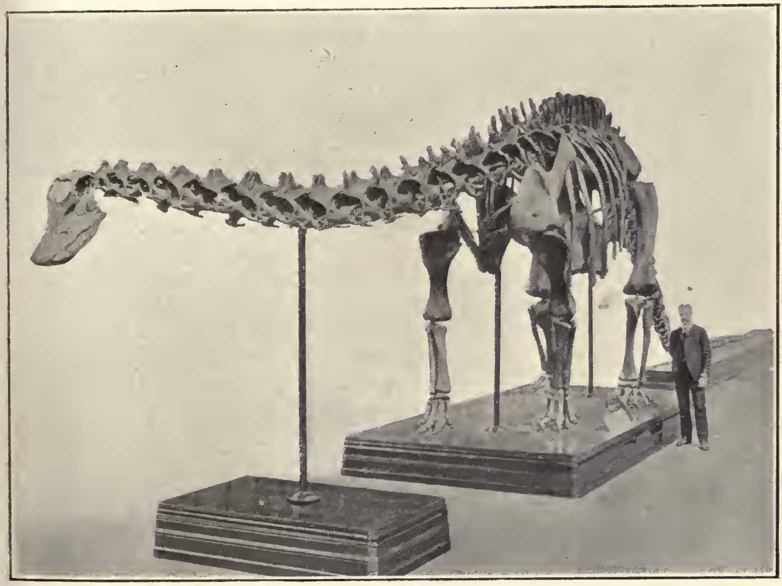


Fig. 2.—Plaster Cast of Restored Diplodocus from the Jurassic of Wyoming.
Total length, 80 feet; height, 10 feet 6 inches.

British Museum of Natural History.

time, and probably advanced and retired according to the severity or amelioration of the climatic influences.

South Africa.—The Beaufort and Stromberg beds, which succeed the glacial tillites in South Africa, were deposited in shallow water, which from time to time received sudden accessions from rain floods. The latter are false-bedded,[1] and there are thousands of instances which record the contemporaneous erosion and deposit,[2] which would be explained by the partial melting of the ice in the warmer seasons every year. The Triassic rocks of Australia frequently exhibit similar current-bedding in a remarkable manner, and overlie sands and gravels in which contorted bedding is very frequent, and those who have examined them on the spot think that the contortion may be due to the stranding of icebergs which preceded the deposition of the current-bedded silts.

Influences on Plant and Animal Life.—The remarkable transformation which took place at the close of the Primary epoch was accompanied by changes equally important in the life of the oceans. The old orders were almost totally extinguished, and their place taken by new species. This was probably due to the refrigeration of the land and sea, and the change from marine to fresh-water conditions, which ensued in the shallower seas.

The Permian exhibits the last traces of primæval life, while the Trias is charged with the remains of plants and animals entirely distinct from all those which preceded them. No contrast can be more marked than between the crustacean fauna of the Jurassic and that of the Primary system.[3] It is probable that the commingling of the older and newer forms of life was due to the mechanical derivation of the rocks in which they are found. In deeper oceans, less affected by the marked terrestrial changes, the transition was less decided. At the same time, many families diminished in number and variety or became extinct. New forms of life made their appearance, and others found the conditions so favourable that development was rapid.

The predominant Cryptogamous plant life of the Carboniferous forests became subordinate in the Temperate zone, and is principally represented in the Permo-Carboniferous transition by fragmentary remains. The place was taken by Pines and Cycads, which, although represented in the earlier rocks by a few species, were predominant in the early parts of the Secondary era.

Reptilian Fauna of Jurassic and Associated Strata.—The epoch we have been considering was one of unique and striking interest. It preserves the fossil remains of the reptiles which inhabited the fresh-water basins of the early Secondary times. Monster Deinosaurs of uncouth proportions and fantastic form lazily dosed upon or near the shores, or waded with ponderous footstep among the

[1, 2] A. W. Rogers, *Intr. to Geol. of Cape Colony*, 1905, pp. 192, 204, 206.
[3] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1903, p. 1119.

pools and streams in quest of sustenance. Pterodactyls were a combination of reptile and bird, whose jaws were furnished with long teeth. Their wings sometimes measured 18 feet from tip to tip, and consisted of a membrane spread from an enormously big elongated finger to the side of the body and little hind legs. The

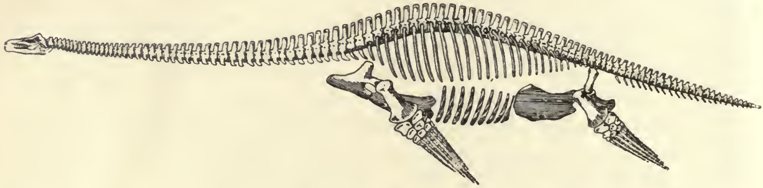


Fig. 33.—Carnivorous Aquatic Reptile, Plesiosaur, 20 feet long. Restoration of Skeleton. (C. W. Andrews.)

skeletons of these strange creatures have been discovered in considerable numbers both in the New and Old Worlds; in South Africa, where 100 different species have been discovered,[1] and as far north as Spitzbergen.[2]

The *Ichthyosaurus* and *Plesiosaurus* were provided with fish-like

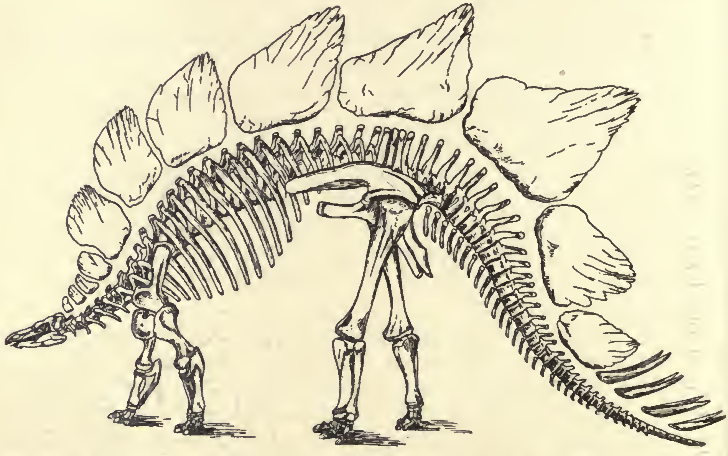


Fig. 34.—Stegosaurus, Restoration of Skeleton, 18½ feet long, from the Jurassic of Wyoming. (Marsh.)

bodies and long tails. The former had an abnormally large head, crocodile like in shape, with little or no neck, while the head of the latter was relatively very small and the neck long. Some of them measured as much as 40 feet in length. They propelled themselves

[1] A. W. Rogers and R. Broom, *Intr. to Geol. of Cape Colony*, 1905, p. 229.
[2] Prof. A. E. Nordenskiold, "Geol. of Spitzbergen." *Geol. Mag.*, 1876, p. 74.

through the water by means of two pairs of strong paddles. The *Brontosaurus* was not unlike those just described in form, but was provided with legs and feet of massive proportions. It went on all fours, and its footprints measured as much as a square yard in area. They were sometimes 50 feet in height, and weighed 20 tons.

The largest specimen of the fossil remains of these creatures is the *Atlantosaurus*, which measures 84 feet in length and 30 feet in height. The majority of them were amphibians, which fed upon the aquatic plants and succulent vegetation, but others were carnivorous.

The disappearance of these reptiles from the earth was as mysterious as the creatures themselves. Either they migrated northwards as the more southern seas changed from fresh to brackish and then salt, or their extinction was finally accomplished at the advent of the transgression of the sea, which took place at the opening of the Cretaceous epoch proper, and there is evidence that both causes may account for the absence of any direct descendants in later ages.

CHAPTER XVIII.

THE CRETACEOUS OCEANS.

Polar Ice commences to melt more rapidly—Transgression of Seas and Melting Ice—Transgression Illustrated—Effects of Transgression in Lower Cretaceous Rocks—Gradual Disappearance of Effects of Erosion in Sediments—Same observed in Australia—Similar Phenomena in South Africa—The Indian Lower Cretaceous—The Lower Cretaceous of N. and S. America—Summary of Facts points to Melting of Polar Ice—Extent of Cretaceous Transgression—Probable Depth of Cretaceous Oceans—Chalk Rocks described—Effects upon Fauna and Flora—Earth Deformation again ensues—Igneous Activity Contemporaneous with Warping of Crust and Lowering of Ocean.

The relative levels of the sea and land at the close of the Jurassic era do not seem to have been very greatly different to what they are now, but their relative distribution was widely different. The land surface was probably small compared with the sea, but had not been so all through the epoch. As the end of the age approached the ice had retreated towards the Poles, and deposits were formed in Caithness, as far north as Franz Joseph's Land, and southward in New Zealand.

We have no means of estimating the proportions or extension of the Arctic ice which remained at the close of the epoch, but the much greater extent of the land which encircled the North Pole at this time, as well as the events which followed, suggests that it was very considerable. The southern limits were no doubt very irregular and extended much further in the highlands than in the lowlands.

The long-continued erosion effected throughout the era just closed, which built up an important series of deposits, gives us, at the same time, a basis for estimating the original proportions of the ice which followed the Permian uplift, the quantity of water stored up in it and available for refilling the oceans, as well as the volume of aqueous vapour that the atmosphere is capable of holding in suspension.

Polar Ice commences to melt more rapidly.—At times in the period we have just reviewed, the absorption of water by the atmosphere appears to have been as great as the supply from the melting ice, so that the seas or basins did not at first rapidly increase in extent. The atmosphere, however, became less and less able to retain the moisture, so that, although the level of the sea rose very

slowly at first, it increased as time went on. At the close of the Jurassic epoch, and before the Cretaceous system was commenced, a remarkable increase in the volume of the oceans is evident. The ice evidently commenced to melt very much more rapidly, and as the atmosphere was saturated with aqueous vapour, a larger proportion of the water remained to supply the oceans.

Transgression of the Seas and Melting Ice.—All through the early part of the Secondary epoch the seas encroached more and more upon the Continent of Europe, and the great lakes and inland seas were filled up. This was the first episode of a general invasion of the sea, which attained its maximum in Europe and Asia in the lower Cretaceous era.[1] The fauna preserved in the rocks of this period, both in northern and southern latitudes, indicate the source and direction of the currents which caused the oceans to rise. The European fauna came from the north (southwards), and the South African from the south (northwards),[2] both from Polar regions. Currents of unusual magnitude were required to bring an Arctic fauna so far into the Temperate zone, which suggests that the vast masses of exceptionally thick Polar ice were melting more rapidly than they did in the Temperate zone during the Jurassic period. The supply of water was consequently derived from Arctic sources, and the seas advanced towards the Poles, so that the transgression chiefly affected the Equatorial and Temperate zones.[3]

The association of the Great Transgression with the break up of the ice age is further supported by the presence of ice-borne erratic blocks in the Cretaceous rocks. Icebergs floated away when the rising sea invaded the highlands, and carried their load of boulders and sand into more temperate latitudes, where they dissolved and released the stones and erratics, which sank and were entombed in the bed of the ocean.

"The chalk of Britain and the North of France not infrequently contain pebbles, and even boulders of granite, quartzite, sandstone, coal, and other foreign rocks. Boulders sometimes occur in the Cambridge Greensand, and similar, though smaller, stones have been found in the Red Chalk of Hunstanton." A granite boulder was unearthed in a chalk pit near Purley, and a block of coal was met with in making the line between Canterbury and Dover. There are striated and polished erratics of glacial origin in deposits which possibly belong to the Lower Cretaceous of the Salt Range in India,[4] although there is some uncertainty as to their true age. All these boulders point to icebergs of large proportions, and even extensive ice flows floating upon the ocean surface for a longer or shorter time, according to their size. The blocks of stone they carried sank to the bottom as they melted.

[1] A. de Lapparent, *Traité de Geol.*, 5th ed., 1906, pp. 1193, 1289.

[2, 3] E. Suess, *The Face of the Earth*, 1904, pp. 287, 292.

[4] H. B. Medlicott and W. T. Blanford, *Manual of Geol. of India*, 1880, p. 497.

The maximum transgression took place between the Jurassic and Cretaceous periods, and its connection with the glacial dispersion seems in a measure corroborated by the relation between the Scotch and English records. The Jurassic rocks of Scotland were largely eroded and destroyed during the interval between the two systems.[1] Erosion cut down through the Oolites, and in some places through the Lias and Trias also, before the Scotch Greensand was formed. The northern denudation was in operation at the same time that the deposition of the Purbeck and Weald clays was taking place, which suggests that there may be some connection between the two, since the Wealden deposits are of fluviatile origin, but whether they were actually derived from the denudation of land as far to the north is beyond demonstration.

The ultimate dispersal of the ice resulted in "one of the greatest changes in the distribution of land and water over almost the whole Earth that is known in geological history. Extensive areas, which had for long periods been continents, were now overflowed by the sea.[2] The wide distribution of the Cretaceous rocks in America "is due to an enormous transgression of the sea over the land. The sea continued to advance northwards, and covered much of the continent," [3] as was the case in Europe and Asia.

The cause of the Great Transgression, which brought on the Cretaceous period proper, was probably the increasing temperature of the lithosphere, which was now recovering from the chilling effects of the glacial epoch. The interior heat slowly extended its influence until it affected the surface and rapidly melted the remaining ice. The water, which had for long ages been filling up the inland lakes and basins, now commenced to link them up into one widespread ocean, which spread itself over all the rocks we have been considering, as well as large areas of still older rocks which had endured the severe erosion.

Transgression Illustrated.—The description of the formation of the Jurassic system in the last chapter also illustrates the result of the Great Transgression or invasion of the sea, and the relations of the Jurassic to the Cretaceous system. The oceans may be compared to an enormous lake, into which detrital sediment had been brought for long ages, and whose level was afterwards considerably raised, and new sediments were laid down upon the older ones. The whole of England was submerged, and the Cretaceous rocks were deposited upon a basement of Jurassic and allied rocks. The transgression is clearly seen in passing from Kent and Sussex, where the Cretaceous system is represented in natural order, towards Devonshire. The lower strata die out one after the other as we pass over the Oolite area, until, in the West, the Cretaceous strata

[1] A. J. Jukes Browne, *Building of British Isles*, 1911, p. 279.
[2] E. F. H. Kayser, *Text-book of Comp. Geol.*, 1893, p. 282.
[3] W. B. Scott, *Intr. to Geol.*, 1897, p. 476.

rest directly upon the New Red Sandstone.[1] In Devonshire the Gault lies upon the Permian.[2] The olive group of the Salt Range of India, if followed in like manner from west to east, lies successively on Jurassic, Triassic, Permian, and the Speckled Sandstone.[3] This overlap is clearly depicted in the illustration (Fig. 31). A similar overlap, due to the same transgression, has been noticed in North Afghanistan.[4]

Effect of Transgression in Lower Cretaceous Rocks.—The coming of the great change has left an indelible impression upon the rocks of the period, as we should expect. All the shallow water deposits so far laid down were themselves denuded, and the sand and silt carried into deeper water, where it settled, and now forms the Purbeck and Wealden beds.

The erosion to which the former owes its origin was a repetition of the events which are recorded in the Oolite rocks of long before. The lower Purbeck was derived from the denudation of the Portland, and contains "an abundant fresh-water and estuarian fauna as well as marine bands." The forests of pines and Cycads, which clothed the ancient land surface, were now submerged. The streams brought pebbles, sand, and silts, eroded from the Portland and Purbeck beds, and deposited them around and among the stools and stumps, and together they now form the Dirt Beds, which are a peculiar feature of these rocks.

The Wealden beds are believed to be of fluviatile origin, and thin out eastwards and southwards like many of the earlier rocks formed in a similar manner.

The erosion stage continued into the Lower Greensand, which is sometimes difficult to distinguish from the Weald clays, and contains fossils derived from it which are mostly water-worn.[5] False bedding is more or less characteristic of these rocks,[6] and they contain many fossils derived from the Oxford and Kimmeridge clays and Portland rocks.[7]

Gradual Disappearance of Effects of Erosion in Sediments.—The effects of the long-continued erosion have left traces of mechanical arrangement of the detrital matter as far as the Lower Greensand. This feature almost disappears in the Gault which

[1] Sir J. Prestwich, *Geol. Chem. Phys. and Strat.*, 1886, vol. i., p. 351; vol. ii., p. 276.

[2] A. J. Jukes Browne, "The Cretaceous Rocks of Gt. Bt.," vol. i., 1900, p. 42. *Mem. Geol. Sur. Gt. Bt.*

[3] Dr. W. Waagen, "The Carboniferous Glacial Period." *Geol. Sur. India, Record*, vol. xxi., part 3, 1888, p. 115.

[4] H. H. Hayden, "The Geol. of Northern Afghanistan." *Geol. Sur. India, Mem.*, vol. xxxix., part 1, 1911, p. 36.

[5] H. B. Woodward, *Geol. of Eng. and Wales*, 1887, p. 377.

[6] W. Topley, "The Geol. of the Weald." *Mem. Geol. Sur. Eng. and Wales*, 1849, pp. 142, 144.

[7] H. B. Woodward, "The Jurassic Rocks of Britain," vol. v., 1895, p. 286. *Mem. Geol. Sur. U.K.*

follows, and settlement of the finely divided matter which had been carried far out to sea commenced. These are the first beds to transgress all the previous ones, which shows that the oceans had now become much deeper, and were less and less affected by the currents. The base of the Gault in Bedfordshire is composed of pebbles, and indicates a certain amount of current action.[1] In Dorsetshire the quartz pebbles vary in size from a pea to 2 inches in diameter. The coarser ones increase in proportion towards the west, and it is believed that they were brought from that direction by strong submarine currents.[2] All the remaining silt afterwards quietly settled as the currents were absorbed in the rising ocean, which had now reached a depth of from 200 to 500 fathoms. The stillness of the sea, which had hitherto been so greatly agitated, is evident in the sponge beds of the Malmstone, into which the Gault graduates. They will only thrive under calm conditions in clear water.

After the deposition of the suspended silt, the water contained a considerable percentage of even more finely comminuted matter, both siliceous and calcareous, some of which was held in solution. The protozoa of the ocean then made use of this, and built up the Upper Greensand.

The Glauconite, of which this formation is so largely composed, and to which it owes its colour, is being formed in the ocean bed to-day along the margins of continental land, where, in approaching thereto, the finest particles of mud commence to make up a decided proportion of the deposit,[3] so that it forms a connecting link between the calcareous oozes and the terrigenous muds proper. This is the same relation which the Upper Greensand bears to the Gault below and the Chalk marls above. The greater depth and distribution of the older formation was due to the exceptional erosion which preceded it. The Glauconite is a hydrated silicate of alumina and iron, and usually occupies the interior of the calcareous tests and casts of foraminifera. It appears that the lime salts are used for the construction of the shells, and the silicic acid for the organic tissues, so that during decomposition and petrification upon the sea bottom the grains of glauconite take the place of these membranes. The calcareous tests have cemented the glauconite grains into a compact and indurated stone.

The Upper Greensand, therefore, represents the last effects of the coming of the Great Transgression, and passes into the Chalk marls which were laid down in a deep sea far from land, and form the base of the Cretaceous system.

Same observed in Australia.—The same evidence is preserved

[1, 2] A. J. Jukes Browne, "The Cretaceous Rocks Gt. Bt.," vol. i., 1900, pp. 285, 412. *Mem. Geol. Sur. Gt. Bt.*

[3] Sir J. Murray and A. F. Renard, *Challenger Reports, Deep Sea Deposits*, 1891, p. 383.

in the rocks formed at the same time in Australia. The Rolling Downs formation covers a large area of Queensland. It is a marine deposit, with occasional fresh-water and plant beds. Conglomerates of water-worn quartz pebbles, embedded in stiff clay, and coarse grits and sandstones are common. The fauna is very mixed, and has been derived from the Lias, Great Oolite, Oxford Clay, Portland Oolite, together with some Cretaceous species,[1] which indicate the time of the erosion which produced the conglomerates and sandstone. Remains of *Ichthyosaurus* and *Plesiosaurus* also indicate a similar derivation.

Similar Phenomena in South Africa.—Conglomerates interstratified with cross-bedded sandstones were deposited upon an uneven surface, in deep valleys of erosion, and around high ridges in South Africa, and are typical of the Neocomian of that part of the world. They lie upon nearly all the older rocks of the Colony, and are usually found in the coastal regions. They contain many large trunks of conifers and cycads related to the Jurassic and Weald plants of other countries, bones of reptiles, and higher up in the series, marine deposits with Cretaceous affinities.[2] These strata are distinctly of fluviatile origin, and represent the period of denudation antecedent to the Cretaceous marine transgression.

The Indian Lower Cretaceous.—A similar accumulation follows the coast line for about 800 miles of the South-eastern Coast of India. It rests upon an old coral reef deposit, which indicates the shallowness of the Jurassic seas of the locality. These reefs were frequently exposed to denudation during the deposition of the lower Cretaceous rocks, which contain calcareous bands derived from them.[3] False bedding is frequent on account of these denuding currents, and the shallow water of the Coral reef period was increased to a moderate depth as the oceans filled up during the deposition of the sands, whose fauna is decidedly of Gault age.[4] Northwards, in Turkestan, the lower Cretaceous consists of conglomerates and cross-bedded sandstones on a large scale.[5]

The Lower Cretaceous of North and South America.—The transgression and the denudation which accompanied it produced similar results in North America. Along the Atlantic and Pacific borders, as well as in the interior, the rocks are a fresh-water formation. There are no marine, but only brackish and fresh-water fossils in the rocks, which now lie between the Trias and marine Cretaceous all along the Atlantic border. In Virginia they contain large rounded and lenticular masses of Jurassic clay imbedded in the sandstone.[6] The base of the Cretaceous of British Columbia and Queen Charlotte

[1] R. L. Jack and R. Etheridge, *Geol. of Queensland*, 1892, pp. 391, 406.

[2] A. W. Rogers, *Geol. of Cape Colony*, 1905, pp. 286, 316.

[3, 4] R. D. Oldham, *Manual Geol. of India*, pp. 234, 236, 244.

[5] R. W. Pumpelly, *Exploration in Turkestan*, 1905, p. 163.

[6] C. A. White, "Correlation Papers—Cretaceous." *U.S. Geol. Sur. Bull.*, No. 82, 1891, p. 93.

Island is marked by massive conglomerates. West of the Coast Ranges, they transgress southwards, the local base being found at successively higher stages, if the system is followed in that direction.[1] These beds are analogous to the sand plains developed during the closing scenes of the Quaternary epoch. The same rocks in North Vancouver rest uncomformably upon an uneven, denuded surface of older rocks, and fill up older valleys of erosion.[2] As far north as Alaska, also, they bear evidence of derivation from, and rest upon, Primary rocks.[3] Further south in California they attain profound proportions, and consist of 20,000 feet of conglomerate, coarse sandstone, and shale, with an associated Jurassic and lower Cretaceous fauna.[4] On the opposite Atlantic coastal plain, the sands progressively transgress landwards from the south-west, so that the younger formation extends farther and farther northwards. The sandy portions are commonly cross-bedded, and exhibit evidence of rapid deposition. Layers of coniferous lignite have been massed together in beds of considerable thickness and extent.[5]

The beds were mainly derived from pre-existing rocks, and represent the period of strong erosion, during which the Jurassic rocks were in some places almost entirely removed, as in Scotland. Fresh-water beds equivalent to the Wealden are widely distributed in parts of South America, in Brazil, Argentine, and in the far West.[6]

Summary of Facts points to melting of Polar Ice.—The Secondary epoch thus opened with a glacial phase, and ice-borne blocks and a fauna derived from Northern latitudes are associated with the Jura-Cretaceous transgression in its initial phases, besides which running water is continually in evidence throughout the intervening period. The absence of evidence of earth movements, together with the fresh-water character of the Lower Cretaceous in many parts of the world also combine with the other facts to prove that the transgression was not due to a submergence of the land beneath the ocean, but to the melting away of the last of the Permian ice. The dispersal of the glaciers of the later Great Ice Age is believed by most geologists to have coincided with a somewhat similar transgression, so that the cause here suggested may be the correct reading of the numerous facts.

Extent of Cretaceous Transgression.—It is instructive to ascertain

[1] G. M. Dawson, "Geol. of the Rocky Mtn. Region of Canada." *Bull. Geol. Soc. Am.*, vol. xii., p. 78.

[2] G. M. Dawson, "Geol. of Vancouver Island." *Geol. Sur. Canada Ann. Rep.*, n.s., vol. ii., 1886, p. 14B.

[3] F. C. Schrader, "Geol. Section of the Rocky Mtns. in Northern Alaska." *Bull. Geol. Soc. Am.*, vol. xiii., 1902, p. 245.

[4] J. S. Diller and T. W. Stanton, "The Shasta-Chico Series." *Bull. Geol. Sur. Am.*, vol. v., 1894, p. 450.

[5] W. B. Clark and A. Bibbins, "The Geol. of the Potomac Group." *Bull. Geol. Soc. Am.*, vol. xiii., 1902, pp. 191, 195.

Eduard Suess, *The Face of the Earth*, vol. i., 1904, pp. 510, 511.

the water surface of the globe in Secondary times. The denudation to which the rocks of this age have since been subjected would render it impossible to do this with more than approximate accuracy, if their distribution were the only guide. It is quite certain that the seas covered the whole of the area now occupied by the early Secondary rocks and deep oceans were spread over the Chalk areas.

The area of the visible earth's surface actually occupied by Secondary deposits forms a large part of the present continents, so that, even if no allowance is made for subsequent denudation, the land which stood above the oceans was small compared with them, relatively small as they now are.

The continent of North America is divided by a line running east of the Mississippi valley in a north-western direction through Lake Winnipeg to the Arctic Ocean.[1] East of this line, or about one-third of the whole, is the only land that could have been above the ocean. The Western plains, including the Rocky Mountain region, remained beneath the seas until the close of the period. The Atlantic and Pacific were probably connected across what is now Virginia, Maryland, and New Jersey. Western Canada and the Western States were at most two large detached islands.

These deposits form an important feature of South American geology. The whole of the Amazon Basin is probably underlain by Cretaceous strata,[2] while most of the mountain ranges of the west and south are partially built up of Cretaceous strata, and were not upraised until long afterwards. The surface of the continent of Australia was originally covered by rocks of the same age.[3]

Turning to Africa, there are large areas of Cretaceous beds in Egypt, Nubia, Algeria, and Sinai. The Atlas range consists of Secondary and Tertiary rocks which have since been thrown up from the ocean bed. It is supposed that the wide region of the Sahara Desert was then beneath the sea. The Secondary series is also extensively developed in the South. There are remnants of a once more widely distributed deposit along both East and West coasts, in Northern Nigeria and in Morocco.

The Mediterranean Sea was then an arm of the Atlantic, and spread its waters southward over the whole of North Africa; at the same time, it covered Great Britain, Southern Europe, Saxony, Poland, the South of Russia, and the Balkan States, and stretched far away eastwards through Asia Minor, Palestine, Arabia, Persia, Baluchistan, and Tibet, covering what is now India, and onwards through China to Japan. It linked up the Eastern and Western Hemispheres with a wide belt of ocean. Rocks belonging to the lower and upper Cretaceous were formed under another arm of the

[1] G. M. Dawson, *The Physical Geol. of Canada*, 1897, p. 17.

[2] E. Suess, *The Face of the Earth*, vol. i., 1904, p. 510.

[3] C. Moore, "Australian Mesozoic Geol." *Quart Journ. Geol. Soc.*, vol. xxvi., 1870, p. 238.

Atlantic, which extended northward into the Arctic circle to the north of Greenland.[1]

It is evident that practically the whole of the earth was now free from the effects of the glacial period. The ice had been melted and absorbed into the waters of the Secondary ocean. The atmospheric moisture which had condensed to form the Permian glaciers was now set free, and the process of sedimentation was destined to commence once more in the wide-stretching oceans. No Polar ice caps obscured the northern and southern extremities of the Earth. The glaciers had played an important part in remodelling the surface features, but now gave place to new processes.

Probable Depth of Cretaceous Oceans.—These particulars are based upon the area actually covered by rocks of Secondary age, but does not agree with that covered by the oceâns. They were much more widely extended. The Cretaceous system is often a complete three-fold series, and required an ocean with abyssmal regions for its construction.

The officers of the Geological Survey of Great Britain have determined that the Gault fauna generally requires a depth of water from 200 to 500 fathoms, the Lower Chalk 860, and the Middle Chalk 1,000 fathoms, so that the oceans gradually increased in depth during the great transgression. M. de Lapparent has shown that the maximum was reached in Europe in the Lower Chalk, but was little greater then than in Gault times.[2]

The Cretaceous rocks of Great Britain are generally confined to the South of England, but the great quantities of chalk flints in the surface drift in many parts of the North of England and Scotland, as well as the Greensand fossils of Aberdeenshire, and the Greensand itself under the basalt in Mull and the chalk of the North of Ireland, point to a former much wider extension of the system. The remains in Aberdeenshire are from the lower and upper Cretaceous, and lie from 300 to 500 feet above sea level, so that the ocean probably attained the same depth there as in the south. The highest peak in the British Isles is 5,400 feet high, and it is probable that its summit was submerged beneath 1,000 feet of ocean at the time the sea reached its utmost limit of depth.

Red Clays, or semi-pelagic type of Cretaceous age, are common to Western Europe, Nubia, Sinai, Arabia, Northern Nigeria,[3] and probably Brazil and Parana in South America.[4] Pelagic quartzites are known in Saxony and Turkestan,[5] where they point to great depths of ocean over what is now continental land. The Cretaceous rocks, moreover, are universally extended, and since few, if any,

[1] A. W. Wallace, *Island Life*, 1892, p. 184.
[2] A. de Lapparent, *Traité de Geologie*, 5th ed., 1906, p. 1425.
[3] Dr. J. D. Falconer, *Geol. of Northern Nigeria*, 1911, pp. 159, etc.
[4] Eduard Suess, *The Face of the Earth*, vol. i., pp 509-10.
[5] Sir R. I. Murchison, *Geol. of Russia and Ural*, pp. 261, 262.

of the present highest mountains of the earth then existed, we may say with certainty that almost the whole of the world was enveloped by the oceans for the greater part of the Cretaceous period after the Great Transgression.[1] There is no other way of accounting for the formation of a world-wide system of sediments, often of great thickness, and the conclusion is strengthened by the considerations to be dealt with in the next chapter.

Chalk Rocks described.—The Cretaceous system is divided into three sections, and is sometimes distinguished by the variety of colouring and chemical composition referred to in a previous chapter. They are the Gault or Upper Greensand, the Chalk marls, and the Chalk. The white Chalk, which forms such a conspicuous feature of the Cliffs of the South of England, is an unique formation from the geological standpoint. Lithologically it is unlike any of the massive rocks which precede it.

The calcareous portions are composed almost entirely of the tests of foramanifera and other marine forms, which indicate that it was laid down in water of moderate depth, and that it is allied to the oozes now being deposited in the present ocean bed down to the 2,000-fathom line.[2] Interspersed within the upper chalk, and often arranged in roughly horizontal layers, are flint nodules, thin sections of which reveal an organic base. They are believed to be the result of molecular attraction, by which the silica dispersed in the mass of the Chalk concentrates about centres of foreign matter; for preference, decaying organic bodies.

Effects upon Fauna and Flora.—The widespread and long-continued oceanic conditions of the Cretaceous epoch are impressed upon the palæontological record. The early Secondary flora is distinct from the later. The records of a land vegetation between the lower fluviatile Cretaceous or Neocomian and the close of the upper marine Cretaceous is almost, if not entirely, lacking. The fossil flora of the Neocomian is of Jurassic affinities, and is frequently found in rolled fragments derived from Jurassic rocks by erosion. In the Lower Greensand and Gault it is represented by drift wood, which probably floated upon the surface of the sea for some considerable time, and eventually settled after the transgression had advanced northwards. The flora of the upper Cretaceous indicates a new beginning, and points to the return of land conditions.

The lower Cretaceous flora resembles the vegetation of the previous ages. Ferns and Cycads were dominant, but Angiosperms or true flowering plants made their debut.[3] The Upper Cretaceous marks the sudden appearance or reappearance of the Angiospermæ,

[1] Eduard Suess, *The Face of the Earth*, vol. ii., p. 540.

[2] A. J. Jukes Browne, "The Cretaceous Rocks of Gt. Bt.," vol. ii., 1903, p. 540. *Mem. Geol. Sur.*

[3] Lester Ward, "Some Analogies in the Lower Cret. of Europe and Am." *U.S. Geol. Sur. 16th Ann. Rep.*, part 1, 1894-5, p. 510.

which now become dominant, while ferns and cycads were subordinate. The new types flourished in various parts of Europe, America, India, and Northern Greenland, where they indicate a relatively warm climate, extending into Arctic regions, instead of the frigidity which now prevails.

The prolific and remarkable fauna of the Jurassic and Lower Cretaceous series of America is in marked contrast to the meagre and restricted fauna of the later epoch. A break in the continuity of vertebrate history more or less marked occurred, and new types of birds and reptiles commenced to make their appearance.

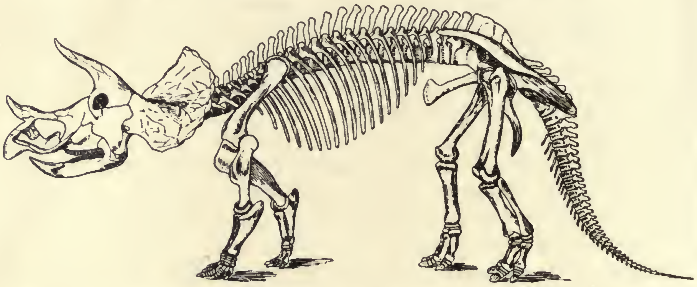


Fig. 35.—Horned Dinosaur, 22 feet long, Upper Cretaceous, Wyoming. (Marsh.)

Earth Deformation again ensues.—It was at the close of the Chalk age that in Europe another change took place in the distribution of land and water, so great and universal that it has scarcely been equalled at any other period of the earth's geological history.[1] In America the period closed with the commencement of the upheaval of the greater part of the Western half of the continent, and probably the down-sinking of the mid-Pacific bottom.[2] "The Cretaceous seas retreated almost all over the world." [3]

The instability of the sea bed in Upper Cretaceous times, anterior to and foreshadowing these greater disturbances in England, has been determined by the palæontological evidence. The oceans, which had been 1,000 fathoms deep in the Middle Chalk era, decreased to one-half that in the Upper Cretaceous, but at one period it was 400, and at others 700,[4] owing to the gradual undulations set up by the volcanic activity far beneath. At the close of the Upper Cretaceous period the seas had not only decreased in depth,[5] but had disappeared altogether from large areas hitherto covered by them, and the undulations increased in magnitude to a general upheaval.

Igneous Activity Contemporaneous with Warping and Lowering

[1, 3] E. F. H. Kayser, *Text-book of Comp. Geol.*, pp. 326, 332.
[2] J. N. Le Conte, *Elements of Geol.*, 5th ed., 1903, p. 568.
[4, 5] A. J. Jukes Browne, "The Cret. Rocks of Gt. Bt.," vol. iii., pp. 371, 376. *Mem. Geol. Sur. Gt. Bt.*

of Ocean.—The cause of this great change was probably two-fold. The internal heat again made itself felt, the climate became gradually more tropical, and the crust unstable once more. The evidence for this comes from India, Abyssinia, and the East and West Indies, where vast floods of lava were poured out from the interior of the earth.

The recrudescence of igneous activity was no doubt due to the addition of so great depths of Cretaceous deposit over wide regions of the ocean bed. The molten interior commenced to melt its way upwards, reducing the rocks above to a plastic state, and eventually breaking through the crust at many points. This was accompanied by earth movements and warping of the crust, which was protruded in some places and depressed in others. At the same time, the internal heat, which had melted the ice long ages before, no doubt continued to evaporate the water of the oceans, and reduced their general level at an increasing rate. The combined upraising of the sea bed and the downward movement of the sea level at last brought about terrestrial conditions, so that while at the beginning of the Secondary epoch, the seas slowly increased in depth, at the close the conditions were reversed.

The upheaval of continental portions of the sea bed was accompanied by the depression of the present ocean abysses, where sedimentation, it is thought, has gone on since the close of the Chalk era. Over the areas of maximum uplift the surface of the land suffered considerable erosion. The movement of the earth was no doubt responsible for some part of this, but it is evident that atmospheric condensation again took place as at former times, and many fresh-water basins were formed in the uplifted areas, in which the Eocene sediments were laid down. These phenomena will be considered in detail in the next chapter.

CHAPTER XIX.

THE CONTINENTS OUTLINED.

The Cretaceo-Tertiary Transition—Igneous Activity and Fluviatile Erosion in India—Erosion and Accumulation of Conglomerates—Upheaval and Denudation of the African Continent—Deformation and Erosion in Australia—Upper Cretaceous History of North America—Igneous Activity and Denudation in West Indies—Upper Cretaceous Transition in Europe—General Results of Post-Cretaceous Deformation—Local Effects of Upheaval—Crustal Elevation and Terrestrial Motions.

THE period of transition between the Cretaceous and Tertiary epochs is marked by events similar to those which took place at the close of the Primary. The land surface was in turn upraised and denuded or depressed, so that beds of sandstone, conglomerate, and coal were laid down. At each epoch a long period of limestone formation was followed by an accumulation of fragmentary rocks. Organic sedimentation gave place to mechanical processes.

The Cretaceo-Tertiary Transition.—The actual order of events was somewhat as follows :—The gradual rise in temperature of the earth's crust, which resulted in the melting of the glaciers, still further increased, on account of the continued addition of sediments, tropical conditions advanced into and beyond the temperate zone, and the level of the ocean was generally lowered, which, combined with renewed earth movements, resulted in the appearance of the land above the ocean, where for long eras it had been submerged. This soil was soon clothed with vegetation of the newer varieties which flourished at this time, and migrated into many latitudes. In process of time the igneous magma increased in energy, and produced a long series of upheavals increasing in magnitude, which, as before, were accompanied by aqueous condensation and surface erosion. The recently formed Cretaceous rocks suffered a greater or less degree of destruction, according to the extent of the upward movement, and volume of the rivers which swept over them.

Igneous Activity and Fluviatile Erosion in India.—In order to best apppreciate the importance of these events it is fitting to commence with a description of what took place in India. Here we meet with a great series of lava flows, which were ejected from the bowels of the earth in the form of molten floods, and spread out upon the land during a period of gradual crustal disturbance. Sheet after sheet was poured forth one above the other, throughout a lengthy epoch, and now form a mass of igneous rock, 200,000 square

miles in area, which is perhaps the greatest single accumulation of volcanic material in the world, and in some places reaches the enormous depth of 6,000 feet. Igneous rocks connected with the same episode have been traced in Sind, Baluchistan, Persia, and Aden.[1]

The Cretaceous rocks were locally disturbed and denuded before the commencement of the volcanic outbursts. Earth movements, as in the coal epoch, affected the atmospheric equilibrium, which was now charged with vapours, and the deluges commenced by which the surface of the older rocks was eroded into valleys, sometimes as much as 1,000 feet deep.[2] The basalt now fills the uneven surface formed by these great valleys without any sediment intervening. The lava flows were accompanied by aqueous torrents, which were precipitated upon them and the neighbouring land, so that fiery flood and aqueous deluge combined in the work of destruction, and masses of rock material were swept from the land and interstratified with the lava.

The fauna and flora entombed in the inter-trappean sediments are in entire agreement with the lithological structure, which was the result of these events. It consists of the remains of insects, fish, and reptiles, all of which are fragmentary, and such as would have occupied the shallow marshes of the preceding era, such as frogs and tortoises. They also contain an abundant fresh-water and estuarian fauna. The whole of the crustacea and mollusca are fresh-water forms, only occasionally is there any evidence of marine flooding. Every fossiliferous sedimentary bed interstratified with the Deccan traps is unmistakably of fresh-water origin, with perhaps one exception.[3] The traps and sediments alternate. The volcanic phase was accompanied and followed by aqueous condensation and erosion of surrounding land. The rains collected in the depressions, and animalculæ thrived for a time in the fresh water, only to be entombed in turn beneath the next flood of lava.

Erosion and Accumulation of Conglomerates.—The effects of these disturbances were felt throughout the length and breadth of India, and are portrayed in the Upper Cretaceous sandstones of each coast of the Peninsula and in Assam.[4] The base of these sandstones consists of an irregularly bedded conglomerate and loose masses of interstratified gravel and beds of rolled pebbles. They fringe the coast line from the mouth of the Godaveri River to Cape Comorin, and contain an abundance of fossil exogenous and cycadaceous wood, in trunks of trees as much as 3 feet in diameter and

[1] E. W. Vredenberg, "The Classification of the Tertiary System of Sind." *Geol. Sur. India, Record*, vol. xxxiv., part 3, 1906, p. 174. E. W. Vredenberg, "The Petrology of the Aden Hinterland." *Geol. Sur. India, Record*, vol. xxxviii., part 4, 1909-10, p. 323.

[2, 3] R. D. Oldham, *Manual Geol. of India*, 1893, pp. 275-6.

[4] Dr. Franz Kossmat, "The Cretaceous Deposits of Pondicherri." *Geol. Sur. India, Record*, vol. xxx., part 2, 1897, p. 82.

60 feet long. The fauna of the upper sandstones contains representatives from the Triassic, Jurassic, and Cretaceous rocks, but the Upper Cretaceous forms predominate. They are the result of the late Cretaceous erosion, and it would seem that the whole of India was upheaved from beneath the sea, where the chalk had probably been accumulating, as in England and other parts of the world. These sands and pebble beds are the remnants of a once widely-distributed and deep formation, which was eroded by stages during the outpouring of the Deccan traps, and by the same agents which formed the intertrappean sandstones, as well as by sheet flooding, during the final stages of the upheaval. The commotion set up in the ocean by the earth movements took a long time to settle down, and tidal waves, no doubt, swept backwards and forwards over the shore, rolled and assorted the pebbles, and finally distributed the sands above them. The powers of denudation were so strong in their action that not only were the Cretaceous rocks largely, if not entirely, removed, but the underlying Jurassic and Triassic rocks also suffered the same fate.

The igneous activity in the Deccan was accompanied by similar events in the Malay Archipelago, and it is believed that the igneous rocks of the whole region are probably of Cretaceous age.[1] Vulcanicity was accompanied by the formation of conglomerates in Borneo,[2] and far to the north in China pronounced folding appears to have been contemporaneous with the accumulation of similar heavily-bedded coarse sediments and sandstones, measuring together 2,000 feet in depth.[3]

Upheaval and Denudation of the African Continent.—The geology of the Continent of Africa at this period preserves the record of similar events. In late Secondary times, violent convulsions rent the whole of the surface throughout the meridional belt, upheaving what is now the main axis.[4] It is inconceivable that these great movements could occur without producing destructive tidal waves in the ocean, and as a similar fringe of Cretaceous rocks to those in India remains along almost the whole of the coast line, it is suggested that the original system was disturbed and eroded, and afterwards carried seaward by currents, which were the direct result of the upheaval. The Cretaceous belt is more or less continuous from Mossamedes in the South, through St. Paul de Loanda, the Congo territory, along the whole of the Western tropical coast, and northwards, where it links up with the Northern coastal belt.[5] It is similarly distributed along the Eastern coast, in British South Africa, Pondoland, Somaliland, and Madagascar.

The South African Upper Cretaceous has been described in detail, and consists of pebbly rocks, with water-worn fragments of

[1, 2] Eduard Suess, *The Face of the Earth*, vol. iii., 1904, pp. 236, 255.
[3] Bailey Willis, *Research in China*, vol. i., part 1, 1907, pp. 296, 297.
[4, 5] N. England, *Notes on the Geol. of Africa*, 1905, pp. 12, 32.

grit, sandstone, and slates, derived from the older rocks of the interior, or shelly limestone, most of the shells of which are rolled and broken, and have had their projecting points rubbed off. They were deposited by strong currents in shallow water at, the bottom of which pebbles and shells were rolled about. When quieter conditions set in, finer silt was laid down.[1] The Pondoland type is the most tumultuous-looking rock in the Colony, and contains blocks of dolomite 20 feet in length.[2] The series extends beyond the present shore line, and outside Durban Bluff it has been met with as much as 300 feet thick.[3] How far these details apply to the rocks extending up the Eastern and Western coasts remains to be seen. Where they are known, as in West Africa, they are remarkably similar to those in the South.

The Upper Cretaceous of Northern Nigeria is a coarse cross-bedded, pebbly sandstone, and was rapidly accumulated during the denudation of the Cretaceous.[4] The regional upheaval at the dawn of the Eocene was marked by the disturbance of the older rocks, and the sandstones now lie upon a folded and fractured surface. The upheaval was followed by intense erosion, which it is believed was active over the whole of the Sudan, and the deposits first laid down were themselves subjected to erosion,[5] which cut down to the older land surface. Intense current action was characteristic of the Cretaceo-Eocene Transition in Egypt, and the two systems are separated by a strong unconformity.[6] Some of the extensive lava fields of Abyssinia are believed to correspond with the flows of the Deccan.[7] The volcanic episode in Aden gradually succeeded the period of disturbance, during which some 2,000 feet of false-bedded sandstone, containing water-worn pebbles, was accumulated. Towards higher levels pebbles of lava and coarse ash are intermingled with the sandstone.[8] These are further links in the similarity of events in the two continents.

Deformation and Erosion in Australia.—The evolution of the Continent of Australia proceeded at this period along similar lines. There was an upheaval after the Rolling Downs stage, and the Upper Cretaceous or Desert Sandstone lies upon it with an unmistakable unconformability. It represents a long period of excessive denudation over an enormous part of the continent,[9] accompanied by marked volcanic activity. Thick-bedded conglomerates, coarse

[1, 2] A. W. Rogers, *Geol. of Cape Colony*, 1905, pp. 325, 329.

[3] F. H. Hatch and G. S. Corstorphine, *Geol. of South Africa*, 1909, p. 316.

[4, 5] Dr. J. D. Falconer, *Geol. of Northern Nigeria*, 1911, pp. 188, 192.

[6] W. T. Hume, "Effects of Secular Oscillation in Egypt." *Quart. Journ. Geol. Soc.*, 1911, p. 131.

[7] Eduard Suess, *The Face of the Earth*, vol. i., 1904, p. 367.

[8] Capt. R. E. Lloyd, "Geol. of the Aden Hinterland." *Geol. Sur. India, Record*, vol. xxxviii., 1909-10, p. 319.

[9] C. Moore, "Australian Mesozoic Geol." *Quart. Journ. Geol. Soc.*, vol. xxvi., 1870, p. 233.

sandstones, clays, and shales, with layers of carbonaceous matter contain fragmentary plant remains, and impressions of large limbs and trunks of trees. In the Gympie and many other districts the sandstones exhibit false bedding.[1] They here overlie masses of basalt, which form an extensive formation, as in India. There were immense outbursts of volcanic activity, and beds of volcanic dust now form a hard sandstone 50 feet thick.[2]

The fossils of this interesting formation are decidedly Cretaceous, while the pebbles were derived from much older rocks, and have travelled great distances.[3] There is every reason for supposing that Cretaceous sedimentary rocks once covered the continent, but were denuded at the close of that period, and laid down again by similar mechanical agencies to those which were instrumental in producing the similar deposits in India and Africa. The land appeared above the ocean, and was then upheaved at the time of the igneous activity, and aqueous deluges built up the conglomerates.

Upper Cretaceous History of North America.—If we turn to the Continent of America, we meet with deposits which indicate that the same events were taking place there. The Laramie, or uppermost Cretaceous, is supposed to represent the period of transition between the distinctly marine end of the late Cretaceous time and the fresh-water submergence that represents the early Tertiary in that part of the world.[4] The system lies in deep valleys of erosion cut down into the older rocks, like those beneath the Deccan traps, and which become deeper and deeper in a north-western direction. These gulleys form a great hiatus between the Cretaceous and the Tertiary. The Cumberland Plateau of Tennessee is believed to be the remnants of a peneplain of erosion, which was produced at the same time.[5]

The sandy beds which were formed by these streams in the Western States rival in extent the great marine formations. Similar conditions of sedimentation prevailed over large areas, and a continuous system of deposit was heaped together in the United States, 2,000 miles from North to South, and more than 500 miles across from East to West,[6] or more than 1,000,000 square miles in area, and was formerly much more widely distributed, since remnants of conglomerate have been noted as far east as the Lake Superior region. The system is in some places upwards of 12,000 feet in thickness, or well over 2 miles. A similar series of coarse sediments covers enormous areas in Saskatchewan and Alberta, within British

[1, 2, 3] R. L. Jack and R. Etheridge, *Geol. of Queensland*, 1892, pp. 542, 544, 548, 555.

[4] H. S. Gale, "Coal Fields of Colorado and Utah." *U.S. Geol. Sur. Bull.*, No. 415, 1910, p. 73.

[5] G. H. Ashley and L. C. Glenn, "Geol., etc., of the Cumberland Gap Coal Field, Kentucky." *U.S. Geol. Sur. Prof. Pap.*, No. 49, 1906, p. 16.

[6] C. A. White, "Correlation Papers: Cretaceous." *U.S. Geol. Sur. Bull.*, No. 82, 1891, p. 146.

North America, and extends to the Arctic Circle at the mouth of the Mackenzie River. The repetition of coal and sandstone beds closely resembles the Upper Carboniferous group, and it is the most important coal-bearing system in the United States. Alternating beds of sandstone, shale, and coal, with fossilised wood and other plant remains, are abundant,[1] and comprise an upper Cretaceous flora which closely resembles the intertrappean flora of the Deccan.[2]

At the outset of the Laramie period there was a comparatively sudden change in the fauna. At a certain horizon in an unbroken succession of strata there is an abrupt disappearance of all the distinctly marine forms, and an equally abrupt accession of brackish and fresh-water forms, which continue through the whole of the Laramie group.[3] The aqueous life was changed first from a purely marine to that of an alternating brackish and fresh-water, and finally wholly fresh-water. The same species are found 1,000 miles apart,[4] so that the new conditions were by no means local, but were due to some widespread cause.

There is a great time break between the Lower and Upper Cretaceous of North America in most parts of the continent. The Lower division, as we have seen, is of fluviatile origin, and contains remnants of the underlying Jurassic land vegetation.[5] It is usually overlain by the Upper Cretaceous, which is also of fluviatile origin, but of vastly more recent age. The fact that it also contains land plants and other terrestrial debris has led some geologists to conclude that the whole of Cretaceous time in America was a time of land surfaces, but, while the lower section is related to the Jurassic, the flora of the base of the Upper division has, like the Indian rocks of the same epoch, even Tertiary affinities, which reveals an enormous lapse of time between the two. The break is represented in Texas by a great depth of marine limestone,[6] which it is probable once extended over the greater part of the Continent, but was disturbed and eroded, and spread out again over the enormous areas now occupied by the Laramie. In no other way, it seems, is it possible to account for the presence of the Upper Cretaceous flora succeeding the rocks with Jurassic affinities, and thus lying at the base of the Cretaceous proper.

Igneous Activity and Denudation in West Indies.—That these results were the product of similar events to those which were operating in India and Australia is proved by the geological record of the West Indies. The history of this region commences with

[1] C. A. White, "Correlation Papers: Cretaceous." *U.S. Geol. Sur. Bull.*, No. 82, 1891, p. 152.

[2] R. D. Oldham, *Manual Geol. of India*, 1893, p. 281.

[3, 4] C. A. White, "On the Relations of the Laramie Molluscan Fauna to the Eocene." *U.S. Geol. Sur. Bull.*, No. 34, pp. 13, 19.

[5] C. A. White, *ibid.*, Bull. No. 82, p. 90.

[6] C. A. White, "Correlation Papers: Cretaceous." *U.S. Geol. Sur. Bull.*, No. 82, p. 109.

long-continued volcanic activities, almost equal in magnitude to the Deccan, and similar to them. The visible basement of the whole of the regions of Jamaica, Cuba, Puerto Rica, San Domingo, and the Virgin Islands consists of the debris of vast volcanic eruptions. A tangled series of tuffs and conglomerates marks the site of this active vulcanism of the late Cretaceous.[1] In the Island of St. Thomas they are as much as 6,000 feet in thickness. The foundation is composed of a vast accumulation of rolled igneous pebbles, land-derived materials, and an enormous mass of other debris. The vulcanism was accompanied by the rapid erosion of the upheaved land and the equally rapid deposition of its denuded remnants. Fossiliferous deposits are sometimes interbedded with the flows of lava.

This series, which indicates alternating conditions of sedimental placidity and volcanic extrusion, implies a conflict between disturbed and quiescent conditions of deposition,[2] and is followed by a great system of loose conglomerates with rounded and water-worn pebbles, sandstones composed of cemented grains of water-worn andesite from the igneous rocks, and bituminous shales and clays.[3] The wild and stormy age of the Upper Cretaceous portrayed in these events ultimately quieted down, and gave place to the deposition of pure white limestone of the overlying Eocene, and there is evidence of a comparatively rapid transition from one to the other.[4]

There is a distinct resemblance between the fluviatile sands, clays, and conglomerates here described, and those of other parts of America. "Along the continental margins of North, Central, and South America there are thick formations of approximately synchronous age, which have a remarkable and suggestive lithological resemblance," and, except in Panama, the source of these materials can be traced to an adjacent back land,[5] so that since the Laramie is represented in the Amazon Basin, as well as in North America, almost the whole of the Upper Cretaceous land surface of the New World was exposed to the denuding forces which accompanied the volcanic upheaval.

Upper Cretaceous Transition in Europe.—The Upper Cretaceous of some parts of Europe often very closely resembles the Laramie of America, and presents a great contrast to the Chalk formation of the Anglo-Parisian basin. The Alpine group consists of sandstones, marls, and coal-bearing fresh-water beds, which rest upon all the rocks of older age than themselves, and even upon the older Cretaceous. The fluvio-marine deposits of this period in Portugal contain fresh-water and estuarian shells, fish, and dicotyledonous plant remains, and overlie the marine limestone. In Germany, sandstone and sandy strata increase in thickness southwards, where they assume gigantic proportions.

[1, 2] R. T. Hill, *Geol. of Jamaica*, 1899, pp. 52, 173.
[3] *Ibid.*, pp. 53, 58. [4, 5] *Ibid.*, pp. 177-9.

The uplifting, which produced such striking results over the continental areas already mentioned, was not so great in some parts of Europe, so that the Cretaceous rocks have not suffered the same degree of erosion, and an almost complete sequence remains. There is, however, evidence in the beds that overlie the Chalk that severe erosion took place at the same time in England. Hundreds of feet of the upper chalk are sometimes missing, and only the flints which formed part of it now remain beneath the next formation. The denudation of the Chalk by the vertical and less destructive deluges, due to the uplift, is more clearly seen here, where the erosion was not so great.

The Chalk flints, which always form the base of the Eocene, are usually in an unrolled state. The finer calcareous material was washed out from among them, and held in suspension in the water, while the flints settled upon the gradually lowering surface as more and more chalk was removed. This is also attested by the Thanet sands which immediately overlie the layer of flints. The angularity and difference between the length, breadth, and thickness of the particles, which lie with their flat faces downwards,[1] indicate that the sand was not rolled along, but the particles were suspended in the agitated water, and then spread out by tidal action or marine currents as the commotion diminished.

Glauconite is frequently laid down during and after periods of erosion, so that the Reading beds somewhat resemble the Lower Greensand. They contain alternate beds of glauconite greensand, sand and pebbles, and finely-laminated or false-bedded clays. Flint pebbles are sometimes associated with estuarian shells, which are mostly broken. The soft clays contain estuarian, marine, and fluviatile shells, together with the remains of gigantic birds, turtles, fish, lignite, and plants. Sometimes they contain masses of comminuted shells and pebbles; at others, the shells are perfect and the bedding even.

These beds reveal the coming of the more moderate transverse currents due to erosion of the neighbouring land. The Oldhaven beds indicate a phase of even stronger currents which followed. The sands contain masses of pebbles and fragments of shells. The pebbles are worn to a remarkable extent, and form a large percentage of the whole. Where the older beds are more fully developed, they are cut into most irregularly by the Oldhaven pebble beds, which have eroded them down to the Chalk.

The uplift at the close of the Secondary epoch was, therefore, of less extent than the one at the close of the Primary, and produced fluviatile erosion instead of glacial. The heavy rains which denuded the Chalk in the south soon brought sand and pebble-laden torrents from the north, which increased in volume, and covered up the

[1] W. Whitaker, "The Geol. of the London Basin." *Mem. Geol. Sur. Eng. and Wales*, 1872, p. 104.

Thanet sands with a deposit containing an increasing percentage of pebbles.

General Results of Post Cretaceous Deformation.—The importance of the almost monotonous repetition of the facts recorded in this chapter compensates for the tedium of their perusal. It is evident that the greater continental areas of both Eastern and Western Hemispheres were upraised above the general level of the ocean. Hitherto they had only been dimly outlined, if at all, but now they were decidedly so, in the beach deposits along continental margins. The water which brought about the erosion found its way to lower levels, and added to the volume of the oceans which collected in the depressed regions. The distribution of land and water after the Cretaceous uplift was much as it is now, the earth was approaching its present configuration.

The whole of the land which was upheaved has not, however, remained dry ever since that time. The disturbances were undulatory and produced inequalities in the new surface. Some parts were elevated more than others, and the crust thrown into gentle folds. When quiet was again restored, new deposits were laid down in the depressions upon the newer sandstones, as well as on much older rocks, where denudation had been excessive. This was the case in India and Africa, where considerable areas were covered with later deposits.

The long process of upheaval of the African, Indian, Asiatic, Australian, and American continents commenced after the Cretaceous system had been built up in the ocean bed, and a new land surface had been clothed with vegetation. This ancient land was gradually thrown into a state of continued unrest. It was alternately upraised and depressed, and wave-like undulations extended far and wide. The movements increased in magnitude towards the great centres of volcanic outbursts, and, as each area was raised and lowered, an unusual commotion was set up in the oceans. Tidal waves of large proportions swept backwards and forwards, and with the subaerial deluges, denuded the Cretaceous and older rocks wherever they were exposed. The effects of these world-wide movements, as they would have appeared to an observer, must be left to the imagination of the reader. It was no isolated phenomenon, and continued for a long period, and produced somewhat similar results to the earth movements in the Devonian and pre-Cambrian times.

Local Effects of Upheaval.—The general deformation of the earth's surface produced important physical features in the form of mountain chains. As the post Primary upheaval had produced the Appalachian revolution in the Eastern States, so the post Cretaceous effected the Coast Range evolution. The underlying rocks were fused from beneath, and melting their way upwards, thrust themselves among the newer sedimentary cover, and warped

and tilted the strata. At the same time a series of folds was produced, running in an Eastern and Western direction across Central China and Tibet. The Rocky Mountains and Himalaya ranges were not thrown up until the close of another geological epoch.

The elevatory movements were not so marked in other localities, and a belt of ocean still remained through Europe, Palestine, and Southern Asia. This region of the earth was upraised from beneath the deep at a much later epoch, and the newer rocks form the crests of some of the highest mountains of the earth. From Sind to Baluchistan and Assam, it is difficult to separate the Secondary from the Tertiary upon any but palæontological grounds, but, at the same time, there is some evidence of denudation between the two, but not to the same excess as in the south.

Crustal Elevation and Terrestrial Motion.—If the conclusions arrived at in this chapter are a reasonable interpretation of the facts, an interesting question of causation is raised by them. If we turn to a map of the world, we see that the continental areas upraised at this epoch all lie within the fortieth parallels of North and South latitude, and that the greater land masses, as well as the centres of volcanic activity, which accompanied the upheaval, are nearer the Equator. It is within these warmer latitudes that marine life is more prolific, and probably more rapidly builds up the ocean bed, so that throughout the Secondary epoch, during which, as we have seen, the climate was zonally differentiated, these particular regions received the greatest additions of sediment.

According to well-established principles, this caused the inner temperature to rise, and brought on the epoch of vulcanicity which was confined to those latitudes, and which implies that the foundations of the earth were in an unstable state. This instability, being confined to that part of the earth where the strains due to rotation round its own axis are greatest, appears to confirm the contention that the centrifugal forces set up by the rotation tend to throw the ocean bed outwards and cause the land at last to appear above the sea.

CHAPTER XX.

THE TERTIARY EARTH.

Increasing Continental Land—Physical Conditions of Tertiary and Coal Measures Compared—Tertiary Fresh-water Lakes—Adaptation of Life to New Conditions—The Great Eocene Mediterranean—The Lower Eocene of England, India, and Africa—Laterite and Eocene Transgression—Climatic Changes in Early Tertiary—Physical Changes mark Close of Eocene—Denudation follows Disturbance—Tranquility again restored in Miocene—Early Evidence of Human Inhabitants of the Earth—Tertiary Progress summarised—Late Tertiary Igneous Revolution foreshadowed.

THE Tertiary system of deposits has been generally divided into four sections, and the name by which each is known refers to the proportion of its fauna, which is more or less distinctly allied to recent species. The percentage of what are now more common increases towards the end of the epoch. In this way the gradual approach of the modern period is traced. The order in which they lie is as follows :—

Pliocene, ...	Still more recent.
Miocene, ...	More recent.
Oligocene, ...	Few recent.
Eocene, ...	Dawn of recent.

American geologists favour a two-fold division, the Eocene and Neocene, but as either is equally serviceable for our purpose, the more usual one is adopted.

Increasing Continental Land.—During the epoch just reviewed considerable additions had been made to the earth's crust. An important geological formation was built up of organic sediments beneath the ocean, and at the close of a protracted chapter of the earth's history the land commenced once again to come into greater prominence. Standing upon the threshold of the Tertiary period and looking back, almost unbroken oceanic conditions had prevailed for long ages ; looking forward, more and more land emerges from beneath the deep.

The scenery at the outset embraced extensive oceans and vast lagoons and marshes. The continents were not so pronounced as they are now, and probably consisted of low-lying plains surrounding and forming divisions between the stretches of shallow water, with

here and there an occasional ridge or fragment of more ancient rock standing out in slightly bolder relief.

This was not destined to be the case for long. The forces which were in operation at the close of the Cretaceous had but commenced their work. As time went on, exceedingly slow undulatory movements, separated by long and quiet intervals, gradually changed the face of the globe. The plains by successive stages became continents, and the marshes and lagoons by the same process were formed into lakes, and lifted above sea level.

The building up of the continents was not accomplished solely by the successive uplifts, but by alternate emergence and subsidence, so that the land gained in altitude by the positive movement, as well as by the addition of sediment, during submergence. Each upward oscillation of the land was accompanied by aqueous denudation, and sand and pebbles were removed from higher to lower levels, and tended to fill up the hollows. The land area was increased and the ocean area reduced, both by the movement and erosion. The earth movements increased in magnitude at long intervals, until the close of the Miocene, when the highest mountain chains of the earth were upheaved. With the continued elevation of the land sedimentation decreased, and the oceans were confined to more restricted limits. In this way the present continents were slowly developed, and the existing relationships between land and water over nearly the whole earth was established.

Physical Conditions of Tertiary and Coal Measures Compared.—The geology of the Tertiary epoch was, therefore, the geology of the land as distinct from the ocean geology of the Cretaceous. The alternate cycles of mechanical and organic sedimentation of the Coal epoch were repeated at this time, and in many respects the two periods are comparable with one another.

" One and the same part of the earth's surface was the floor of the sea during one phase of this period, and was covered by marine sediments. During the next phase it was again land, and was then covered by the brackish deposits of lagoons. Fresh-water lakes formed in the new land, while at a still later period, in consequence of another invasion of the sea, marine sediments were again laid down on the last. The manifold alternation of marine, brackish, and fresh-water deposits is certainly explained in many cases by the great number of earth movements during the Tertiary period in Europe, Asia, and America." [1]

Tertiary Fresh-water Lakes.—The transition from the Cretaceous to the Eocene, as well as from one Tertiary epoch to another, and even from the Tertiary to the Quaternary period, was an erosion

[1] E. W. Vredenberg, " The Classification of the Tertiary System of Sind." *Geol. Sur. India, Record,* vol. xxxiv., part 3, 1906, p. 177. E .F. H. Kayser, *Text-book of Comp. Geol.*, 1893, p. 327. T. C. Chamberlain and R. D. Salisbury, *Geology*, vol. iii., 1905-6, p. 193.

interval. The earth movements, which were responsible for these changes in the character of deposit, were accompanied, as at previous times, by cooling of the earth's crust, and consequently the atmosphere, so that moisture was precipitated. Each cycle commenced with rapid sedimentation and the formation of fresh-water lakes. The Tertiary has, in fact, been termed the age of Lakes by the American geologists. During certain periods large parts of the European, American, and Asiatic continents were covered by fresh-water lakes of vast dimensions.[1] The denudation by the torrents which filled the lakes in America affected the whole of the continent, and much debris, which was started seawards by the swift waters in the higher lands, found lodgment long before it reached the sea, and was spread out over wide areas.[2] The results of these events will be referred to in the progress of the narrative.

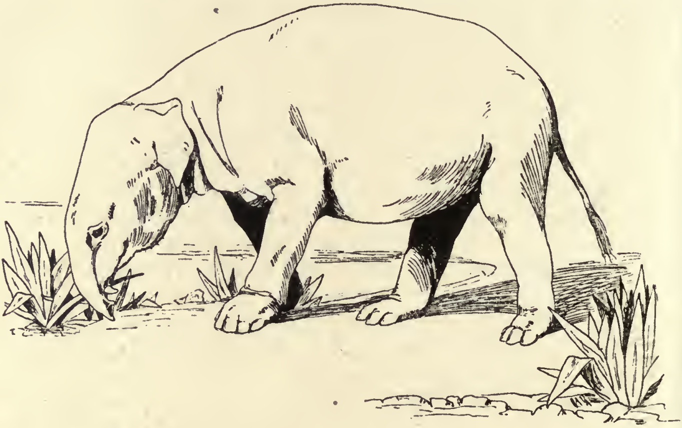


Fig. 36.—Moerithrium, restored. Primitive Elephant, about the size of a large Newfoundland. Middle Eocene of Egypt.

Adaptation of Life to New Conditions.—The opening of the Tertiary chapter of geological history was, not only the threshold of the development of the present physical geography of the earth, but was the embryo stage, so to speak, of recent organic life. New orders came into being adapted to the new conditions. The change of environment was accompanied by changes in, and additions to, the earth's fauna and flora. The re-emergence of the land was attended by the introduction of a land fauna, and in other respects the harmony between life and its environment, and its adaptation to it, was as complete as at the beginning.

The evolutionary progress was restricted in Cretaceous times,

[1] Eduard Suess, *The Face of the Earth*, vol. iii., 1904, p. 59.
[2] T. C. Chamberlain and R. D. Salisbury, *Geology*, vol. iii., 1905-6, p. 204.

especially in the vertebrate kingdom, on account of the great transgression. With the return of terrestrial conditions progress was at first more rapid in the vegetable kingdom, and a diversified flora existed and extended well into North Greenland, where a large number of species have been recorded, including poplar, walnut, plane, laurel, fig, cinnamon, magnolia, and eucalyptus. This mingling of temperate and subtropical types in the far north indicates a relatively warm climate and considerable migration. With the approach of the Tertiary era the higher kingdoms had made important progress, and the character of the fauna reveals the geographical transition

Carnivorous, Herbivorous, Insectivorous, and Primate mammals made their appearance after the land had been formed for their reception and clothed with vegetation for their sustenance. The progenitors of the cat, dog, horse, elephant, ape, and others all came upon the scene in the early Tertiary. Geologically speaking, their introduction was not only sudden, but they appeared in great numbers and in considerable variety.[1] The Bird Class in the Cretaceous was represented only by reptilian birds and ordinary water birds. In the Tertiary, however, the reptilian birds had all disappeared, and many new kinds appeared, land birds as well as water birds. Woodpeckers, parrots, owls, eagles, swallows, secretary birds, cranes, flamingoes, and pelicans enjoyed the varied landscape, according to their own peculiar taste—land, air, and sea ; lake and marsh and mountain peak, as well as night and day. Insect life was absent or restricted in Secondary times, whereas in the Tertiary it was peculiarly abundant and prolific. Fauna suited to the littoral conditions abounded, and many others declined in importance or ceased their existence.

The Great Eocene Mediterranean.—As at all previous periods, however, the ocean, with its ceaseless resources, has been the prime agent of the earth's architecture, and we have to take up the narrative again in the bed of the early Tertiary seas. The causes which effected earlier transgressions were again in operation at the dawn of the Eocene, so that the seas again advanced over much land that had for a time been laid bare, but did not reach the proportions of earlier transgressions. Europe, Asia, Africa, and America all experienced a partial return of the sea, and as an instance, the English rocks are an example. There is a progressive overlap of the Reading and Oldhaven beds above the Thanet sands, which form the bed of the Eocene, and indicate the rise of the water level. The tidal wave continued its progress and overspread a large portion of the South-east of England, which had only recently been exposed to denudation.

At the outset of Tertiary times, at least, the whole of the South-

[1] J. N. Le Conte, *Elements of Geol.*, 5th ed., 1903, p. 542. E. F. H. Kayser, *Text-book Comp. Geol.*, 1893, p. 327.

east of England up to a shore line running from Hampshire to Norfolk was beneath the ocean. The Tertiary beds which lie within this area have been enormously denuded, and it is probable that they once extended much further, and that the sea transgressed far to the north. This ocean also covered nearly the whole of Belgium and France, and stretched away eastwards, across the heart of the Old World, from the Alps to the Carpathians, into Asia Minor, Persia, India, Bengal, and China. Southward, it flooded Algeria, Morocco, and Egypt.

The Eocene rocks of this great Mediterranean Sea are almost of equal importance to the Cretaceous system as a geological formation. The lower portion of the series was deposited in abysses, which were some thousands of feet deeper than those in which the Cretaceous, which sometimes underlie it, were laid down, as the deep sea Eocene follows the shallower sea Chalk. The earth movements, combined with the atmospheric condensation, was the cause of this. The bed of the Secondary ocean was depressed, and the basin so formed acquired the water which denuded the surrounding high lands at the time the passage beds were accumulated. The sedimentary deposits laid down within this basin have since been upraised in greater part, and now form the highest ranges of the earth.

The Lower Eocene of England, India, and Africa.—The London clay, which follows the Lower Eocene transition rocks in England, is from 400 to 480 feet thick, and with the upper members of the series, which are now missing on account of denudation, must once have formed a great system. It is a stiff blue and slate-coloured clay, and being highly siliceous, resembles the pelagic marls of other systems. It is very uniform in texture, and was laid down in gradually increasing depth of water, so that what is now the Eastern counties was at that time an exceptionally deep part of the ocean, as it had been in the Red Chalk era.

The lower Eocene of India is a clay-like ferruginous rock, which passes into hæmatite, and weathers into Laterite.[1] This is a mottled, brown, red and yellow, porous rock, much impregnated with peroxide of iron, and has been called an iron clay.[2] It does not consist of the debris of pre-existing rock, but probably originated as a pelagic ooze, resembling those described in an earlier chapter, and since it passes into the base of the Eocene, was, no doubt, deposited in the deepest parts of the oceans of that period, and was upraised during the late Tertiary revolution. It now covers large tracts of country in India, and caps the summits of hills and plateaux of the highlands. In the Deccan area it always surmounts the highest lava flows, and is seldom lower than 2,000, and never more than 7,000, feet above the present sea level. The low level Laterite is a pebbly conglomerate, and was formed by the denudation of the plateau

[1, 2] R. D. Oldham, *Manual Geol. of India*, 1893, pp. 306, 370, 388.

beds long after their upheaval, and shows that they were once a much more important formation than now appears to be the case.

The remarkable similarity between the geology of India and Africa, which has already been noticed in the period just closed, is repeated here. The whole of the Ghazal region, as well as the A Zande plateau of Western Tropical Africa, and a belt stretching for great distances north and south of the Congo mouth, are also covered by laterite in the form of a ferruginous conglomerate and clay.[1] A similar rock is conspicuous in the great Congo basin. It constantly occurs in patches on the rises of undulating country, and was evidently deposited in horizontal layers of no great thickness over extensive areas, and has since been denuded and channelled by the rivers which drain the basin. The origin of these beds has caused much controversy, but their evident relation in every respect to the oceanic oozes of existing seas strongly suggests that they owe their origin to organic causes, but long exposure has much altered their appearance.

Laterite and Eocene Transgression.—This explanation of the derivation of these iron clays needs some further substantiation, since many geologists hold that it is produced by the decay *in situ* of much more ancient rocks under the peculiar atmospheric conditions of the tropics. This conclusion receives very little support, however, from direct or indirect evidence, since laterite of almost the same composition overlies black sandstone,[2] as in the Pab range of India, the Deccan Traps in the Central Provinces, the Fundamental Gneiss, and even upon Coal seams.[3] It is difficult to see how these very diverse kinds of base rock could produce even a clay of approximately similar composition.[4]

Trap rocks of the Deccan weather into black, cotton soil, and not into laterite,[5] and it has been pointed out that where it overlies the trap the impression conveyed by the appearance is that there is not a gradual passage downwards from completely formed laterite to the underlying rock, with an intermediate stage of rock in a state of partial decomposition, but that laterite is a distinct formation.[6]

Where gneiss has decomposed *in situ*, it produces a soft yellow clay, which, on account of the variation in the original rock, the basic portions can, though reduced to clay, be easily distinguished from the acid veins.[7] A pseudo laterite is formed, in which the

[1] N. England, *Notes on Geol. of Africa*, 1905, pp. 23, 32.

[2] E. W. Vredenberg, "Pseudo-Fucoids from the Pab Sandstones." *Geol. Sur. India, Record*, vol. xxxvi., part 4, 1908, p. 246.

[3] E. W. Vredenberg, "Geol. of Sarawan, Jhalawan, Mehran, and the State of Las Bela." *Geol. Sur. India, Record*, vol. xxxviii., part 3, 1909, p. 204.

[4, 5] R. D. Oldham, *Manual Geol. of India*, 1893, pp. 381, 413.

[6] L. Leigh Fermor, "The Manganese Ore Deposits of India." *Geol. Sur. India, Mem.*, vol. xxxvii., part 2, 1909, p. 373.

[7] Sir T. H. Holland, "The Charnockite Series." *Geol. Sur. India, Mem.*, vol. xxviii., 1898-1900, p. 185.

original quartz laminæ often remain in their pristine position enclosed in a ferruginous mass.[1] So that laterite has no resemblance either to the rocks upon which it lies or the products of trap and gneiss decomposition.

On the other hand, laterite has been formed from Lower Tertiary ferruginous clays, and the change has been actually observed where it exists as a crust upon the surface of the clay.[2]

The evidence favouring the sedimentary origin of the original clay or limonite is that it is believed to be mainly of such origin by competent authorities[3] who have first-hand knowledge of it. It sometimes contains "ghosts of fossils," is often stratified,[4] is restricted to well-defined levels, and not infrequently contains nodules of manganese and iron ore,[5] like the oceanic red clays of the Pacific, and, finally, its position corresponds with the base of the Tertiary, into which it sometimes passes. The rocks themselves, therefore, appear to represent the result of the post-tertiary transgression, which is recorded in other parts of the Peninsula of India and Africa, and in many places throughout the world.[6]

Climatic Changes in Early Tertiary.—The exceedingly protracted period during which the ocean population was building up the plastic clays, the red ferruginous clays and sands, and the Nummulite limestone, after their transgression, was so protracted that the climate exhibits some variation between the lower and upper beds. The climate at the close of the Cretaceous epoch approached the ultratropical in our own latitude, but its severity was somewhat mitigated by the general cooling of the atmosphere required for the heavy rains of the period of erosion, so that the lower Eocene was approximately tropical. The flora of the European continent was much like that of Africa, Australia, and the West Indies. Plants analogous to the Cocoa-nut palm grew where London now is,[7] while tropical marine shells, plants, and reptiles are discovered in the London clay.[8]

Much of the earth's surface appears to have waved with greenery and enjoyed a peculiarly equable climate. "So far as we can judge from the plant remains of our own country, the climate seems to have been almost tropical in the lower Eocene period." Further

[1] R. Bruce Foote, "The Geol. of South Travancore." *Geol. Sur. India, Record*, vol. xvi., part 1, 1883, p. 24.

[2] P. N. Bose, "Geol. and Min. Resources of the Rájpiplá State." *Geol. Sur. India, Record*, vol. xxxvii., part 2, 1908-9, p. 175.

[3] R. Bruce Foote, "Geol. Notes on Traverses through Mysore State." *Mysore Geol. Dep., Mem.*, vol. i., 1900, p. 6.

[4] E. W. Vredenberg, *loc. cit.*, vol. xxxvi., p. 244.

[5] F. R. Mallet, "On Laterite and other Manganese Ore." *Geol. Sur. India, Record*, vol. xvi., part 2, 1883, p. 116.

[6] Dr. Franz Kossmat, "The Cretaceous Deposits of Pondicherri." *Gecl. Sur. India, Record*, vol. xxx., part 2, 1897, p. 79.

[7] A. de Lapparent, *Traité de Geol.*, 5th ed., 1906, p. 1488.

[8] Sir C. Lyell, *Elements of Geol.*, 6th ed., 1865, p. 290.

North, and within 22° of the Pole, a flora grew which included oaks, poplars, birch, plane, lime, hazel, walnut, as well as water lilies, pond weeds, and iris. Altogether, there were about one hundred species of flowering plants. Still nearer the Pole, and only 8° therefrom, the remains of poplars, birch, hazel, elm, eight species of conifers, including swamp cypress and Norway Spruce, are included in the flora.[1]

In early Eocene times the Arctic flora wore a temperate aspect, while in the present temperate zone it was almost tropical, which is a slight modification of that suggested by the close of the Upper Cretaceous. A further decrease seems to be suggested by the Upper Eocene flora of Hampshire. It consisted of cypress, yews, Californian pines, fan palms, eucalyptus, fig, cinnamon, plane, poplars, oak, elm, and beech. There are date palms with the fruit, fruit stalks, and flower sheaths, in a remarkable state of preservation. The tree trunks were garlanded with large tropical creepers, and the shades of the forests supported an undergrowth of magnificent tropical ferns.[2] After the climate had been reduced from extra tropical in the Upper Chalk to slightly under tropical in the lower Eocene, and temperate in late Eocene, it once more advanced to distinctly tropical in these latitudes. This appears to have taken place somewhat rapidly, since the older trees just referred to are temperate, while the younger creepers are tropical.

Physical Changes mark Close of Eocene.—This is a repetition of what took place at the close of the Secondary period, and it was accompanied by a repetition of the other events which took place at that time. "The internal activity long dormant in Europe again commenced to make itself felt in the eruption of serpentinous rocks. The bed of the ocean was again upraised, and a marked period of fluvio-marine conditions ensued once more, by which means the Oligocene beds were formed. The land conditions of the Upper Eocene was followed by another upheaval and a withdrawal of the sea, but the atmospheric condensation soon caused the seas to advance again, and the continent of Europe was like a great archipelago in the Miocene. In America the close of the Eocene was marked by a withdrawal of the sea, while during the Miocene it again advanced as in Europe.

Denudation follows Disturbances.—The Oligocene, again, forms passage beds between the Eocene and Miocene, and is very similar in lithological structure throughout Europe. In the Isle of Wight it consists of a deep series of alternate fresh-water, estuarian, and marine marls,[3] clays, and limestone, composing an essentially fluvio-marine system, which bears the same relation to the Eocene as the Reading and allied beds do to the Cretaceous.

[1] A. W. Wallace, *Island Life*, 1892, p. 184.
[2] E. Westlake, *Outlines of Geol. of Fordingbridge*, 1889, p. 11.
[3] C. Reid and A. Strahan, "Geol. of Isle of Wight," 1899, p. 124. *Mem. Geol. Sur. Eng and Wales.*

The exposed Chalk and the newly-formed and upraised Eocene System in England was deeply denuded in the Oligocene time, and it is likely that much of the newer strata corresponding to the Nummulite Limestone of the Mediterranean Sea was swept away. The Lower Bagshot beds overlying the London clay at Brentwood and elsewhere represent the products of just such events. The lowest layers consist of closely-packed gravel, almost entirely composed of Chalk flints, while at the top they are mixed with more sand, and there is much false bedding. As, however, similar periods of erosion have since occurred, the beds may have been re-arranged again and again after the Oligocene era.

Tranquility again restored in Miocene.—As the Tertiary ages continued, the continental portions of the earth gradually increased in proportion, on account of the repeated crustal movements and the filling up of the Early Tertiary fresh-water lakes with sediment. The Oligocene transition inaugurated another period of tranquility, the products of atmospheric condensation collected in the Miocene depressions, and a further sedimentary cycle commenced, and fresh-water deposits were again laid down.

The Province of Auvergne then occupied such a basin, within which sands and conglomerates of the older rocks of the locality form the base, and are followed by red marls and sandstone, grey and white marls, and, finally, fresh-water limestone. The Miocene lakes of the North American continent, of Germany, and the Molasse in Switzerland were all fresh-water. Miocene deposits are not represented in England, but their existence in other parts of the world indicates that this period was of long duration. There was an interval of comparative freedom from the greater volcanic manifestations and earth disturbances, so that tranquil conditions prevailed generally.

Early Evidence of Human Inhabitants of the Earth.—The Pliocene rocks are of quite a different character, and point to the return of fluviatile agencies, and, as they contain the first distinct evidences of man's presence upon the earth, it is probable that the earliest human inhabitants of the earth lived in the late Miocene, before the mechanical forces came into operation which account for the accumulation of the Pliocene gravels to be described in the next chapter.

The relics which point to man's presence upon the earth at this time are principally flint implements of a rude type. Many of them have been met with at the base of the Crag series of Norfolk, which "have unquestionably been worked upon by human agency."[1] They bear distinct evidence of the currents which heaped up the gravels, as many of them have been water-rolled and some semi-pebbled. In what way these currents which account for the accumulation of the Pliocene gravels, referred to in the next chapter, affected

[1] J. Reid Moir, *Flint Implements of the Sub-Crag Man*, 1911, p. 25.

the human inhabitants of this part of the world, it is impossible to say in the present state of our knowledge, and it is a subject upon which it is not safe to speculate.

These Eolithic implements have been long known in Kent and Hampshire and other places in this country, as well as in America and Burma and South Africa,[1] and have been the subject of much controversy. There has been some considerable reluctance in accepting them as proof of the existence of man at such an early age, but the corroborative evidence of the East Anglian Eoliths, renders this exceedingly probable. They have been obtained in considerable numbers from the high-level gravels upon the North Downs,[2] and in the neighbourhood of Fordingbridge [3] and Dewlish.[4] The Kent im-

Fig. 37.—Typical Eoliths. (J. P. Johnson.)

plements were water-rolled during the denudation of the chalk, and those from Hampshire are taken from gravels which have been much rolled. Besides the flints, several crania of deer, all of which have been broken in one way, by a violent blow on the skull between and at the base of the horns, have been discovered in the upper Pliocene,[5] as well as numerous sharks' teeth, perforated like beads in a manner resembling the custom of savages at the present day.

There is sufficient reason, therefore, for placing the earliest progenitors of the human race in the early Pliocene, or more probably in the late Miocene epoch, but whether the inhabitants of the earth in those far-off days were fully-developed human beings, or only half-man and half-beast, it is impossible to say with certainty. It has been claimed for certain bones discovered in Pliocene beds of Java that they represent an intermediate form between the ape and man in a low state of culture, but although the evidence is suggestive of this, it is far too scanty to base so important a conclusion upon. It is at the same time convenient to think of the

[1] J. P. Johnson, *The Prehistoric Period in South Africa*, p. 16. Dr. Franz Noetling, "The Occurrence of Chipped Implements in the Upper Miocene of Burma." *Geol. Sur. India, Record*, vol. xxvii., 1894, p. 101.

[2] B. Harrison, *Eolithic Flint Implements*, p. 16.

[3] E. Westlake, *Pal. and Eolithic Imp. in the Valley of the Avon*, 1902.

[4] C. J. Grist, "Some Eoliths from Dewlish and the Question of their Origin." *Journ. Royal Anthropological Inst.*, 1910.

[5] Lord Avebury, *Prehistoric Times*, 1900, p. 400.

Pliocene populace as semi-man ; neither man nor beast, physically developed perhaps, but not mentally.

It should, at the same time, be pointed out that high authorities are strongly opposed to the recognition of human agency in these Eoliths. Prof. Sollas, for instance, says that " on the important question of man's first arrival on this planet, we may for the present possess our minds in peace, not a trace of unquestionable evidence of his existence having been found in strata admittedly older than the Pleistocene,"[1] or Quaternary age, which succeeded the Pliocene.

Tertiary Progress Summarised.—Looking out upon the earth's surface throughout Tertiary times, the seas first encroached upon the extended landscape of the Upper Chalk, on account of the intensely heavy rains which fell at the time. Towards the close of the Eocene era the waters receded at the same time that more land was upraised by volcanic energy. This was followed by yet another rainy period and the erosion of the new land. The seas partially transgressed the land again, and reduced them to the state of an archipelago. Sedimentation then proceeded tranquilly throughout the Miocene, and towards the end of this period, or perhaps earlier, the earth was first inhabited by a human population. Finally, a mighty uplift of the ocean bed took place, only comparable with the Carboniferous upheaval.

Late Tertiary Igneous Revolution Foreshadowed.—The slow progression of the influence of the igneous interior during Secondary and Tertiary times is thus clearly portrayed in the rocks of these systems. After the refrigeration of the earth's envelope in Permian times, the temperature of the crust slowly increased, and the heat manifested itself in various ways. At the close of the Jurassic epoch the mantle of ice was finally dispersed. At the close of the Cretaceous, earth movements, first of undulation, and then of upheaval and depression of the ocean bed took place, and were accompanied by vulcanicity. The climate still continued unusually hot, but was moderated by the earth movements. A repetition of these events closed the Eocene, while in the Oligocene igneous matter again broke through with great energy, and produced dyke intrusions and lava flows. The climax was reached at the close of the Miocene, when colossal movements took place, and large areas of the ocean bed were upraised into lofty mountain chains, which brought on glacial conditions once more in high altitudes.

The augmentation of the inner temperature, with the consequent manifestations of volcanic energy, appears to have had a direct bearing upon the variation of the climate. During the Secondary period it increased from the frigid to the tropical, in what is now the temperate zone. There were slight oscillations between tropical and semi-tropical, during the Eocene and Miocene, but after the uplift at the close of the Miocene it again returned to frigidity in

[1] W. J. Sollas, *Ancient Hunters*, 1911, p. 69.

the same latitudes. While, therefore, the rising inner temperature directly influenced the outer atmosphere, the consequent elevatory movements had just the opposite influence. Each uplift moderated the climate, and the greatest upheaval brought on the severest glacial conditions. As in the Permian, the previous humidity of the atmosphere paved the way for the formation of *nevé*, where the uplift was great enough, or of rains, where the elevation was less.

The increasing energy of the molten magma caused serious instability of the rocks as it melted its way upwards. The more stable rock masses supporting the newer strata above were reduced to a plastic condition, until the whole shell was rendered liable to seriously feel and respond to the distorting forces of the exterior gravitation, as it had done on a previous occasion. The result was a repetition of all the phenomena which characterised that period, and which are described in the next chapter.

CHAPTER XXI.

THE TERTIARY MOUNTAINS.

Volcanic Activity—Dyke Intrusions—Faulting—Contortion and Folding—Mountain Building—Erosion due to Uplift and Retreat of Sea—Increasing Effects of Denudation seen in East Anglia—Similar Results in Mississippi Valley—Denudation during Himalayan Uplift—Genesis of Present Continental Drainage—Great Ice Age—Miocene and Permian Sequence of Events Compared—The Periods of Deformation Illustrated—Repetition of Various Cycles.

THE climax to which the gradual increase of igneous activity throughout Secondary and Tertiary times led up, seems to have equalled, or even surpassed in some respects, similar events that had taken place in the past history of the earth. Much of the continental land that had been upraised at the close of the Primary epoch was now covered by great depths of Secondary and Tertiary strata, and in regions where the rocks were thickest mountain ridges were thrown up from the depths of the ocean, so that the fractured and inclined rocks of Tertiary age often lie at high altitudes. These movements determined the present relationships of sea and land, so that the Tertiary period practically completed the constructive history of the earth. The present chapter is a description of the phenomena associated with the mountain building.

The lava flows, the dyke intrusions, the contortion and faulting of strata, and the mountain building, which marked the close of the Primary age, were all repeated during the latter part of the Tertiary epoch.

Volcanic Activity.—" After a long quiescence, during the Mesozoic period, volcanoes broke forth with great vigour, both in the Old and in the New Worlds. Vast floods of lava were poured out." [1] The basaltic columns of the Giant's Causeway, of Antrim, Mull, and Skye were outpoured in the form of lava in the Oligocene era, as were the similar rocks of the Faroe Islands, Iceland, and other places far into Arctic Greenland. The site of many an ancient volcano has been located in Scotland. " The great Tertiary volcano of Mull was probably 14,500 feet in height." [2] It was towards the close of the Oligocene period that the grand eruption of the andesite lava of the Miocene began, through the agency of which a volcano of larger dimensions than Etna was gradually built up near Schem-

[1] Sir A. Geikie, *Text-book of Geol.*, 3rd ed., 1893, p. 1221.

[2] J. W. Judd, " The Secondary Rocks of Scotland." *Quart. Journ. Geol. Soc.*, vol. xxx., 1874, p. 259.

nitz, in Hungary. "It was formed, doubtless, by some great paroxysmal outburst."[1]

The puys and volcanic plateaux of the Auvergne district are of the same age.[2] Lofty tracts of Secondary strata have been preserved from the denudation to which the locality has been exposed at a subsequent period by the basalt covering of great thickness and widespread proportions.

"The Miocene epoch in the Rocky Mountain region of British Columbia was a time of notable volcanic eruption, producing both effusive and fragmentary rocks and, towards the close, flooding great tracts with basaltic flows."[3] Some of the most enormous accumulations of ejected volcanic material are found among the Tertiary rocks of North America. They are as much as 11,000 feet in depth. The great volcanos of Mexico and the Cascade Mountains were active at this time.[4]

These rocks occupy an area of about 50,000 square miles in Great Britain. Iceland is a volcanic island of the same age, 45,000 square miles in area, which, together with the Faroes, probably formed a continuous bed of lava 175,000 square miles in surface. In Idaho alone, lava beds cover 200,000 square miles of territory.

Similar events are recorded in Japan, where great manifestations of igneous activity and volcanos broke forth with great vigour, forming many volcanic chains.[5] Molten rocks poured out at the same period are now piled up in numerous mountain masses throughout Queensland, New South Wales, and Victoria,[6] as well as in New Zealand, where eruptive rocks cover extensive areas in the south.[7]

Dyke Intrusions.—Basaltic flows are usually associated with dyke intrusions. "It seems most likely that these dykes were formed in vertical or highly-inclined fissures, that had been opened in the crust of the earth, into which liquid and plastic rock has welled upwards from the interior."[8] They are "connected with innumerable fissures in which the basalt arose, and from numerous points in which it flowed out at the surface."[9] The overlying basalt has in many areas been denuded away, leaving only the dykes to tell the story.

"A dyke crosses the Oolite sandstone of Yorkshire, and is probably of Miocene age. It passes through the Lias, New Red Sand-

[1] J. W. Judd, "On the Ancient Volcano of the District of Schemnitz, Hungary." *Phil. Mag.*, ser. 5, vol. i., 1876, p. 563.

[2] Sir J. Prestwick, *Geol.: Chem., Phys., and Strat.*, vol. ii., 1886, p. 386.

[3] G. M. Dawson, *Geol. of Canada*, 1889, p. 44.

[4] W. B. Scott, *Intr. to Geol.*, 1897, p. 513.

[5] *Outlines of Geol. of Japan*, 1902, p. 76.

[6] R. L. Jack and R. Etheridge, *Geol., etc., of Queensland*, pp. 575, etc.

[7] James Park, "Geol. of Cromwell Subdivision." *Geol. Sur. of New Zealand, Bull.* 5, 1908, p. 63.

[8] P. Macnair, *Geol. and Sc. of the Grampians*, vol. ii., 1908, p. 86.

[9] Sir A. Geikie, *Scenery of Scotland*, 1901, p. 143.

stone, Coal, and Millstone grit, and a great thickness of Silurian rocks." A geological map of the South of Scotland shows a profusion of these veins of igneous matter. They are in some cases of Carboniferous age, while others belong to the Tertiary. One of the latter passes across Loch Lomond, and since its eruption has been planed away by ice to the present level.

Faulting.—Extensive faulting took place at the same period. In Ireland the age of certain faults has been determined as later

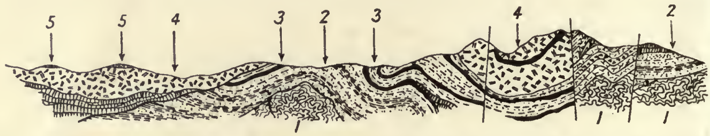


Fig. 38.—Tertiary Folding, Faulting, and Lava Flows in the Rocky Mountains of Washington. 10 miles.—1, Schists. 2, Eocene sandstones and shales. 3, Sills of igneous rock. 4, Lava flows. 5, Miocene strata.

than the Miocene and older than the Pliocene. The upper Miocene of New Zealand are crossed by dislocations "produced during the folding of the beds." [1] The same is also true of the New World. "An abrupt wall facing East, three hundred miles long, and causing a drop in the Nevada Country of from three thousand to ten thousand feet, dates from about the close of the Eocene period.[2]

Great tectonic movements took place in Japan about this time which shook the foundations of the islands. The crescent was

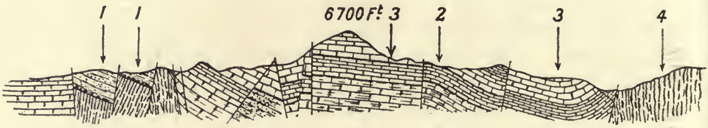


Fig. 39.—Early Tertiary Folding and Faulting in the Rocky Mountain Region of Arizona. Section, 3 miles in length.—1, Cambrian Quartzite. 2, Devonian Limestone. 3, Carboniferous Limestone. 4, Schists. (F. L. Ransome, *U.S. Geol. Sur., Atlas Folio*, p. 112.)

flexed and broken at its middle, and the result was the partition of North and South Japan.[3] A great lateral thrust broke up the linear arrangement of many mountain masses.

The great fault of the Jordan Valley was formed in the Miocene.[4] A system, of which this forms a part, extends southwards through Mount Hor, the Nile Valley, and onwards towards Central Africa.

Contortion and Folding.—The crustal movements, which were a

[1] J. H. Adams, "The Geol. of the Whatatutu Subdivision." *Geol. Sur. N.Z., Bull.* 9, 1910, p. 33.

[2] Sir J. Prestwich, *Geol.: Chem., Phys., and Strat.*, vol. i., 1886, p. 254.

[3] "Outlines of Geol. of Japan." *Geol. Sur.*, 1902, p. 75.

[4] E. Hull, *Geol. of Palestine*, 1886, p. 104.

consequence of the violent volcanic activity of this period, were accompanied by marked rock plication. In the Alps of Switzerland and New Zealand strata of Tertiary age were involved in the contortion to which the rocks of these countries were subjected. Among the Swiss Alps, Jurassic, Cretaceous, and Eocene strata have been thrown up, during some of the most remarkable mountain building throes of which we have any knowledge.[1] In New Zealand, a thin band of Miocene, many miles in length, is interbedded between

Fig. 40.—Folds in Cretaceous Rocks of the Neuenalp. (A. Heim, *Geol. Karte der Schweitz*, vol. xvi.)

the folds of rocks of Primary age.[2] "It runs across hill and dale, rising in many places to a height of nearly 6,000 feet above the sea, in others descending to a little over 1,000 feet. It is a feature of extraordinary interest, and so far as is known at present, there is nothing comparable with it, except the narrow wedge-like strips of Nummulite limestone (Eocene) involved in the Malm on the

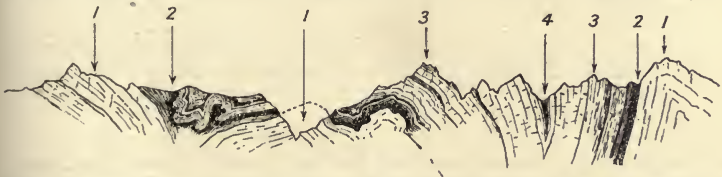


Fig. 41.—Folding in Jurassic Zone of the Himalayas.—1, Muth Quartzite. 2, Permian. 3, Trias. 4, Jurassic. (C. L. Griesbach, *Mem. Geol. Sur. Ind.*, vol. xxiii.)

west side of the Jungfrau."[3] At one point on the shore of Lake Whakatipu, the originally horizontal strata have been thrown into an almost vertical position, and at the same time bent round into the form of the letter "S."[4]

[1] Lord Avebury, *Scenery of Switzerland*, p. 291.

[2, 3, 4] James Park, "Geol. of Queenstown Subdivision." *Geol. Sur. N.Z., Bull.* 7, 1909, pp. 61-65.

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The extraordinary manner in which these Tertiary beds have been twisted and warped affords ample evidence of earth movements on a vast scale, after the close of the Miocene, in the southern latitudes. The highly inclosed, folded, and warped state of the rocks of the same age in Spitzbergen, at the other extremity of the earth, with those of the south, indicates the widespread effects of the late Tertiary upheaval.[1]

Mountain Building.—The main significance of the involvement

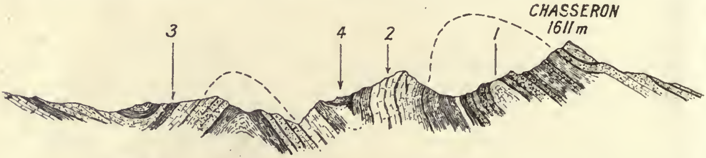

Fig. 42.—Folded Jurassic Rocks of St. Croix, with Fragment of Tertiary involved.—1, Inferior Oolite. 2, Kimmeridge. 3, Purbeck. 4, Tertiary. (T. Rittener, *Geol. Karte der Schweitz.*, vol. xiii.)

of these Tertiary deposits, high up in the Alps of the Northern and Southern Hemispheres, lies in the evidence it affords of the age of the mountains of those regions. In the New Zealand instance, "we have a portion of a marine littoral involved in a great crust fold, and elevated to a height exceeding 5,000 feet above the sea, affording the clearest proof that a sea floor existed in the early Miocene, where the Richardson Mountains now stand."

The latter part of the Tertiary epoch witnessed the development

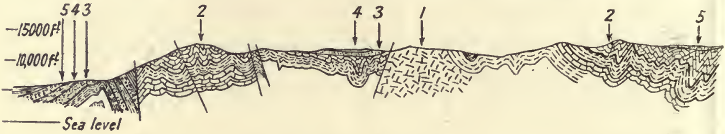

Fig. 43.—Section, 150 miles in length, illustrating Tertiary Folding and Uplifting of the Tian Shan Plateau.—1, Granite. 2, Folded Primary rocks. 3, 4, 5, Folded and elevated Tertiaries. (Ellsworth Huntington, *Exploration in Turkestan.*)

of the present distribution of land and sea, and the final upheaval of most of the great mountain chains of the globe. Some of the most colossal disturbances of the terrestrial crust in the history of the earth took place at this time. The whole of the gigantic forces to which the mountains of Central Asia, which contain the highest peaks of the world, owe their origin, must have been increased in late Tertiary times.[2] That vast chain, extending from the Pyrenees to the Alps and onwards into Asia, including the Balkan Peninsula,

[1] Prof. Nils Nordenskiold, "Geol. of Spitzbergen." *Geol. Mag.*, 1876, p 256.

[2] H. B. Medlicott and W. T. Blanford, *Manual Geol. of India*, 1880, pp. 56-7.

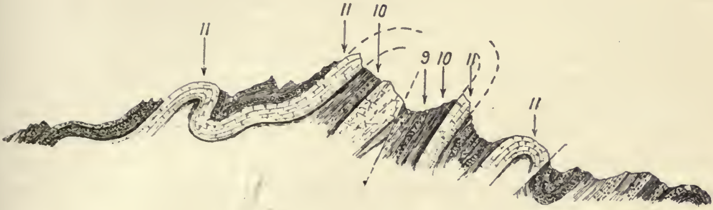

Fig. 44.—Folding in Tertiary Zone of Himalaya Mountains. (A. B. Wynne, *Mem. Geol. Sur. India*, vol. xi.) (See Fig. 47 for key.)

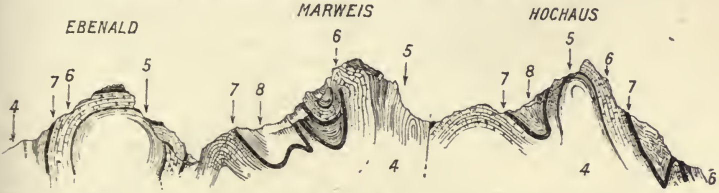

Fig. 45.—Folding in Cretaceous Zone of Swiss Alps. (A. Heim, *Geol. Karte der Schweitz, N.F.*, vol. xvi.) (See Fig. 47 for key.)

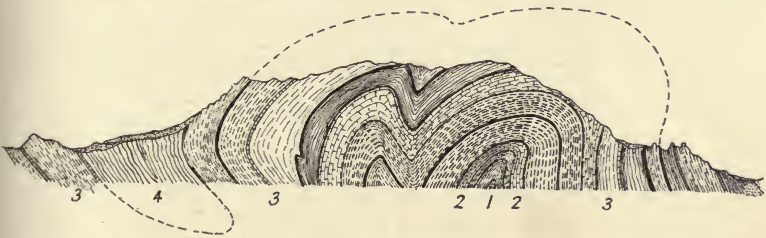

Fig. 46.—Folded Strata pierced by Weissenstein Tunnel. (A. Baxtorf, *Geol. Karte der Schweitz, N.F.*, vol. xxi.) (See Fig. 47 for key.)

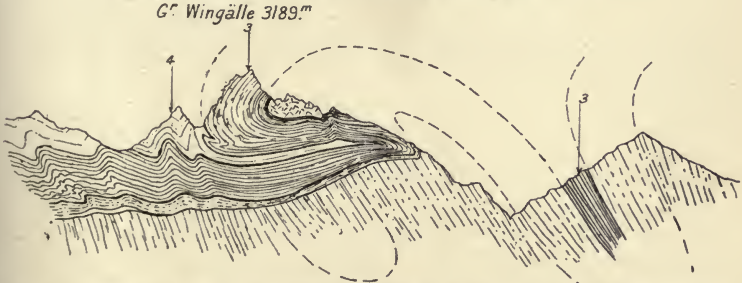

Fig. 47.—Section across the Grosse Wingälle, about 7½ miles, with inverted Jurassic Strata and involved Eocene. (A. Heim, *Mech. der Gebirgsbildung*, 1878.)—1, Trias. 2, Lias. 3, Jurassic. 4, Tertiary. 5, Neocomian. 6, Aptian. 7, Greensand. 8, Chalk. 9, Variegated Sandstone. 10, Red Clays. 11, Nummulite Limestone.

the heights of Asia-Minor, the Caucasus, Palestine, and the Himalayas, and onwards to Japan, received their principal plication and uplift in the Miocene and towards the close of the Pliocene period. The bed of the great Mediterranean Sea, which stretched as a belt round the heart of the Old World throughout the Cretaceous and early Tertiary epochs, was upheaved into a mountain system, and produced some of the most remarkable physical features of the globe. The deepest parts of the ocean probably produced the loftiest mountains.

The mountain building in Central Europe and Asia only affected the British Isles in a minor degree. The Chalk and associated deposits were thrust upwards into undulations, one of which formed the Wealden dome, of which only the remnants remain in the North and South Downs. In the West, ridges and hollows were formed, while in the Isle of Wight the Tertiary beds were engulfed in an earth fold, and now lie in a vertical position.

The geological survey of the Grand Cañon district of America shows that there was a series of earth movements there, the culmination of which was an uplift of colossal magnitude in the Miocene. The upheaval in its later stages was paroxysmal, and the enormous areas of horizontal strata were affected to the extent of no less than 12,000 to 18,000 feet.[1]

The Andes and Cordilleras and Rocky Mountains, which form the backbone of North and South America, reaching from the Arctic circle to Cape Horn, were upheaved during the same epoch. The Drackensberg, Stromberg, and Zwartzkop heights, which form the principal features of South African geography, and which contain manifold dykes and various centres of intrusive rocks, were elevated to their present position during the same period.[2]

The present condition of the strata, which were disturbed by the earth movements at this time, varies considerably. The rock systems of California just mentioned, for instance, suffered little deformation. They were far enough removed from the axis of upheaval to be little affected by horizontal stress. When, on the other hand, we enter the region of the Alps, Himalayas, or the Rocky Mountains, "so enormous has been the contortion, that, as may be seen along the northern Alps, the rocks for thousands of feet were completely inverted, the inversion being accompanied by the most colossal folding and twisting. The massive sedimentary formations were crumpled up and doubled over each other, as we might fold a pile of cloth." [3] "We find the rocks curved, crumpled,

[1] C. E. Dutton, "Tert. Hist. of Grand Cañon Dist." *U.S. Geol. Sur., Mono. II.*, 1882, p. 72.

[2] G. W. Stow, "Geol. Notes in Griqualand West." *Quart. Journ. Geol. Soc.*, vol. xxx., 1874, p. 665.

[3] Sir A. Geikie, *Geol. Sketches*, 1882, p. 346.

PLATE IX. [To face page 212.

Folded Triassic Beds near Spiti, Central Himalayas.

Indian Geological Survey Photograph.

fractured, inverted, tossed over each other into yawning gulf and towering crest, like billows arrested at the height of a furious storm."

Erosion due to Uplift and Retreat of Sea.—The result of the Tertiary upheaval, as portrayed in the rocks which succeeded it, is one of the most interesting records of the geology of the period. If we could imagine portions of the continents of Europe, Asia, and America slowly emerging from beneath the ocean depth as they did, we could also conceive that the seas would retire from these areas in all directions in the same way that water runs off a flat surface that is lifted horizontally from beneath it. The seas retreated in this way, and swift currents swept towards all points of the compass, carrying loose stones and earth with them, some of which were deposited near the coast line. This torrential phase of the denudation took place before the mountains had reached a sufficient altitude for the formation of Glaciers, so that the Pliocene pebble beds sometimes underlie the glacial moraines which were formed during the succeeding geological epoch.

The effects of these currents is clearly depicted in the composition and distribution of the Pliocene rocks. As the mountain system of Switzerland, the Carpathians, and the Tyrol were uplifted in successive stages, great commotion was set up in the oceans, as in Old Red and Torridonian Sandstone times. The seas gently surged backwards and forwards at first, but the alternate movement towards, and then away from, the centre of disturbance increased in energy, until, when the crests appeared above the sea level, it swept down the mountain sides and away to the oceans never to return. The overlying and less consolidated rock was carried along by the torrents and laid down in the surrounding plains towards the confines of Europe.

The base of the Pliocene in the South of France was essentially a period of transport.[1] In Germany the beds are entirely fluviatile, while in Italy they are marine and fluviatile. They are widely distributed in Greece, and consist of marls and clays full of land and fresh-water shells huddled together in successive platforms, having been hurried by torrential floods through thickets, and were accompanied by stones in rapid motion.[2] The gravels and clays are also largely developed in Bosnia, Roumania, Bulgaria, and the South of Russia. They sometimes lie at high levels above the sea, whither they were swept by the surging water.

Increasing Effects of Erosion seen in East Anglia.—The havoc wrought by the currents which came across the North of France and impinged upon the coast of England is difficult to describe. The Coralline Crag represents the submarine wash of the early phase of the commotion. It contains an abundant flora, which can only

[1] A. de Lapparent, *Traité de Geol.*, 5th ed., 1906, p. 1640.
[2] Sir A. Geikie, *Text-book of Geol.*, 1903, p. 1295.

flourish in strong currents, and is more or less current-bedded: sometimes at high angles, and at others in flowing curves.[1] This phase lasted for a long period for the growth of coral beds, but the commotion increased, and strong currents swept round the Wealden Anticline which had recently been upraised, bringing fauna from the Mediterranean region [2] which was mixed with sand and pebbles eroded from its surface and deposited in the quieter water on its northern slopes, and are now known as the Lenham sands. They lie from 600 to 800 feet above the sea level, and are represented at similar levels in Belgium.

In Red Crag times swift surging waves swept to and fro over the older Eocene deposits in the Eastern Counties now exposed to their denuding action, eroded them as well as the newer Coralline Crag into deep channels, so that the Red Crag is full of broken shells derived from the Coralline Crag and the London Clay. It is false-bedded, and there is a constant tendency for the lower Red Crag itself to be eroded and its shells redeposited at a slightly higher zone.[3] The upper Crag is also extensively false-bedded, and contains rolled flints, and was itself again denuded before the Forest Bed was deposited above it.

The force of the waves seems then to have somewhat diminished, which allowed the fine silt and sand and other debris to settle in uneven and false-bedded layers. The seas then retired from the area, where they had thrown up so much debris, leaving a litter of stools, trunks, and limbs of trees brought from the continent, and which had been cast out upon the shore. The aqueous condensation brought on by the uplift overspread the new surface with another layer of land-derived silt and sand, or eroded it into channels and hollows, in which fresh-water beds were afterwards deposited.

The silt and debris of the older Cromer forest bed is composed of alluvium and estuarian deposit from the Rhine Valley, and contains many pebbles and rock fragments from that locality, which is in a direct line between the centre of the mountain building disturbance in the Tyrol which produced the currents and Cromer, and directly connects the formation of the Crags with the Miocene upheaval. It is also noteworthy that the southern coast line of Kent and Sussex crosses this line at right angles, and suggests that the obstruction offered to the enormous volume of water which swept towards it resulted in the partial cutting of the Straits of Dover and the initial erosion of the Weald.

Similar Results in Mississippi Valley.—In North America the Pliocene are developed along the Atlantic and Pacific borders, and consist of well-stratified gravels and clays with pebbles from the older rocks, which appear to have been deposited in moving water

[1, 2, 3] C. Reid, "The Pliocene Rocks of Gt. Bt.," 1890, pp. 36, 52, 96. *Mem. Geol. Sur. Gt. Bt.*

during a period of great erosion.[1] Great banks of coarse gravel were accumulated on the western flanks of the Sierra Nevada ranges, where they sometimes rise and cap the summits of ridges from 5,000 to 7,000 feet in altitude.[2] An area of about 200,000 to 250,000 square miles in the southern States is covered by a blanket of pebbly and sandy clay, which is usually cross-bedded and irregularly stratified. It is sometimes a shelly marl which was massed together by strong currents, and rests upon a surface of all the older rocks up to the Miocene, which was eroded before it was laid down upon them.[3] The age of this formation is probably Pliocene, and it contains pebbles and boulders of eruptive rocks [4] common to the outflows which had recently taken place, and also Archean pebbles transported from the far North, which were carried along the direct line of the axis of the Mississippi valley to these beds in the lower Mississippi and Petit Island on the Gulf shore,[5] in the same way that rock fragments from the Rhine valley were carried to the Norfolk coast.

As the ridges of hills emerged or were further uplifted, currents of water sped eastwards, westwards, and southwards. On the Pacific border they impinged upon the flanks of the Sierras, plunged over and around them on the way to the ocean. The hills were eroded on the eastern flanks, facing the currents and the sand and gravel deposited on the Western slopes and in the valleys, while in the South it was spread out in a sheet upon high and low ground alike. Similar irregularly deposited gravels were no doubt continuous throughout the Atlantic coastal plain, and they cap all the higher terrain levels of the "western shore" of Maryland, Washington, and northwards. East of Washington a high level terrain is capped by beds consisting mainly of large pebbles and sand with a buff-coloured loamy matrix. Further east, the proportion of loam increases, and the pebbles decrease in size and number.[6] Adjacent to the large drainage depressions, the formation consists of somewhat coarser materials, which together indicate that the deposit was derived from landward sources.

The Coast of British Columbia was eroded into deep valleys, which now form fiords.[7] The materials were swept far out to sea, and now form part of the shelving plateaux which surround

[1] F. Beecher, "The Structure of a Portion of the Sierra Nevada of California." *Bull. Geol. Soc. Am.*, vol. ii., 1891, p. 64.

[2] J. E. Spurr, "Descriptive Geol. of Nevada." *U.S. Geol. Sur., Bull.* 208, 1903, p. 64.

[3, 4] W. H. Dall and G. D. Harris, "Correlation Papers: Neocene." *U.S. Geol. Sur., Bull.* 84, 1892, pp. 306, 675.

[5] Warren Upham, "The Succession of Pleistocene Formations in the Mississippi and Nelson Basins." *Bull. Geol. Soc. Am.*, vol. v., 1894, p. 90.

[6] N. H. Darton, "Meso. and Ceno. of Eastern Virginia and Maryland." *Bull. Geol. Soc. Am.*, vol. ii., 1891, p. 445.

[7] W. H. Dall and G. D. Harris, "Correlation Papers: Neocene." *U.S. Geol. Sur., Bull.* No. 84, 1892, pp. 260, 275.

the coast. Middleton Island, off the coast of Alaska, was built up of this debris, as it consists of horizontal layers of Pliocene strata.[1]

Denudation during Himalayan Uplift.—Pliocene rocks in India present quite similar features, and often consist of a conglomerate of large pebbles of all the older rocks up to the Eocene and Miocene, and was formed by the denudation which accompanied the upheaval.[2] They extend along the whole length of the Himalayas, and were evidently formed during the earth movements to which these ranges owe their formation. Although they are distinctly of fluviatile origin, they are involved in the folds which accompanied the uplift, of the region. Similar rocks cover an enormous area in Burma, in which the same evidence of fluviatile agencies is preserved. Everywhere in this part of the world silicified tree trunks, mammalian remains from the pre-existing land, and other fossils are entombed, and near the coast it passes into a more estuarian and then a marine deposit.

Genesis of Present Continental Drainage.—This phase of geological history witnessed the early development of the present drainage systems of the continents. As we have seen, the existing relation of continent to ocean was largely developed in the early Tertiary. The land increased as the seas decreased in superficial extent. The oceans of the Secondary became the seas of the early, and the lakes of the late Tertiary. From this time onwards the continental river systems were evolved by successive stages. The pre-glacial or Pliocene rivers were quite distinct from existing ones. The Lafayette torrents eroded a channel 6 miles wide, or three times the width, and 100 to 150 feet deeper than that occupied by the Mississippi flood plain to-day, and similar old valleys are numerous in other parts of the New World,[3] and many valleys of Europe have Pliocene gravels at their base.

The lower Nile wore its way deep down into the tableland formed of Eocene Limestone to a depth of from 800 to 1,000 feet, forming a valley with an average breadth of some 10 miles.[4] Beds of muds, clays, shale, and false-bedded sandstone containing a mixture of Cretaceous, Eocene, and Pliocene fauna and flora in the South owe their origin to similar causes.[5]

[1] W. H. Dall and G. D. Harris, "Correlation Papers: Neocene." *U.S. Geol. Sur., Bull.* No. 84, 1892, p. 275.

[2] R. D. Oldham, *Manual Geol. of India*, 1893, p. 314.

[3] H. F. Bain, "Geol. of Washington County." *Geol. Sur. Iowa*, vol. v., 1895, p. 160. H. F. Bain, "Geol. of Polk County." *Geol. Sur. Iowa*, vol. v., 1895, p. 278, etc. R. Chalmers, "Surface Geol. of New Brunswick." *Geol. Sur. Canada Ann. Rep.*, 1885, p. 16 gg. C. A. White, "Geol. of Pike and Monroe Counties." *Second Geol. Sur. Pa., G.* 6, p. 62. J. N. Le Conte, *Elements of Geol.*, 5th ed., 1903, p. 586.

[4] N. England, *Notes on Geol. of Africa*, 1905, p. 23.

[5] F. H. Hatch and G. S. Corstorphine, *Geol. of South Africa*, 1909, p. 322.

Captain Durton has determined that the major part of the denudation of the Cañons took place in the Miocene epoch immediately succeeding the final and paroxysmal uplift.[1] The ice period in that part of the world, he says, was rainy rather than glacial. The district is beyond the terminal moraines that mark the southern extension of the glaciers, so that the erosion of the Secondary strata into Cañons was commenced in the early Pliocene retreat of the sea, and continued by the torrential rains which accompanied the formation of glaciers in the north.

There were thus three distinct phases of the denudation which was effected at this time. That due to the emergence of the land was followed, first by aqueous erosion brought on by atmospheric

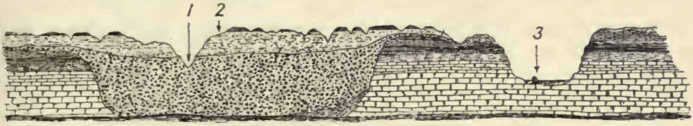

Fig. 48.—Section showing Comparison between Pre-Quaternary and Present Valleys of the Mississippi River, in South Iowa.—1, Till in old valley. 2, Drift. 3, Mississippi gorge. (C. R. Keyes, *Geol. Sur. Iowa*, vol. iii.)

condensation while the land was rising, and this again by glacial abrasion when the maximum altitude was reached. All three phases were fulfilled in the great centres of uplift so far referred to, but in less elevated and more equatorial regions, where conditions were not so favourable for the formation of ice, the fluviatile action continued for longer periods.

Great Ice Age.—The next important event in the order of geological succession was a long period of glaciation, which followed close upon the uplifting of the mountain systems. Glaciers freely appeared at the moment when the Alps and so many other chains had just acquired their principal relief.[2] The previously humid climate, together with the general cooling, covered the mountainous districts with snow wherever the altitude permitted it.

The deposits formed by the glacial abrasion prove that glaciation commenced as soon as the ice was consolidated. The Blue Bottom deposits of New Zealand occupy the same position in relation to the Miocene as the Permian do to the Carboniferous. They consist of stratified clays and marls, much of which is composed of rock meal from the adjacent hills deposited in sea water. "Not infrequently, in the upper portions, isolated erratics occur. Many of these boulders are fairly well rounded, while others are sharply angular and often present knifelike edges. Some of the most

[1] C. E. Dutton, "Tert. Hist. Grand Cañon Dist." *U.S. Geol. Sur., Mono. II.*, 1882, p. 100.

[2] A. de Lapparent, *Traité de Geol.*, p. 1784.

resistant of them show deep glacial striæ."[1] This accumulation is supposed to be of Miocene or Pliocene age. Pliocene mollusca are well represented in them, so that they record two stages in the denudation which followed the Miocene upheaval of New Zealand. The aqueous erosion which produced the lower clays and sands was followed by glacial which effected the striation upon the erratics.

Miocene and Permian Sequence of Events Compared.—The chain of events which culminated in the Pliocene glaciers followed one another in the same order as they had done ages before in the Permian epoch. In each case we find that a world-wide and relatively hot climate was followed by great earth convulsions. Associated with each set of movements were igneous outbursts, dyke intrusions, and faulting. At both periods, the elevatory movements were followed by excessive refrigeration of the earth's crust and the formation of extensive glaciers, which at once began to abrade and erode the peaks upon which they rested. The earth passed from the Eocene and Miocene tropics to the Pliocene Arctics, as it had from the Carboniferous heat to the Permian cold.

The phenomena associated with the uplifting are so world-wide in their occurrence that we have every reason for supposing that the uplift was equally so. Continental masses of the earth's crust were upraised from the ocean bed as well as the mountain ranges. It was indeed a second expansion of the entire envelope, although the extent of the movement was apparently not so great as in the Permian epoch. The expansion again produced excessive cooling within the crust itself, and the moisture-laden atmosphere condensed in the form of snow upon Northern and Southern Hemispheres. The second Glacial epoch had dawned upon the earth. The climate was again changed from the mild humidity of the Tropics to the severe cold of the Poles.

The direct connection between the uplifting of mountain chains and glacial conditions, which has been pointed out by the officers of the New Zealand Geological Survey, has already been alluded to. This is perhaps the most reasonable explanation of the cause of the Glacial epoch, and confirms the opinion of other writers. It is based upon observation in the field, and is in keeping with what we know of the glaciers of the Alps and other regions. They are invariably confined to the highest and, therefore, coldest localities. Even Mount Kenia, 19,500 feet, which is situated almost upon the Equator,[2] has its capping of perpetual ice and snow, and glaciers extend downwards, and terminate at a mean level of 15,500 feet. The "Pliocene uplift of South Island, New Zealand,

[1] Sir J. M. Bell, "Geol. of Hokitika Sheet." *Geol. Sur. New Zealand, Bull.* 1, 1906, p. 87.

[2] Dr. J. W. Gregory, "Glacial Geol. of Mt. Kenya." *Quart. Journ. Geol. Soc.*, vol. l., 1894, p. 521.

was accompanied by increasing refrigeration and glacial invasion."[1] "The Alps rose higher and higher, and soon great glaciers came creeping down from the snow fields."[2] It is difficult for us then to avoid the conclusion that both the Permian and Pliocene glaciation were directly due to the uplifts which took place at these periods.

The Periods of Deformation Illustrated.—An instructive generalised section in the Alpine region shows the effects of the two periods of maximum earth upheaval and rock plication with great clearness. Contorted Primary strata have been denuded, and upon their eroded edges a succession of Secondary rocks have been laid down, which form the Alps of to-day.

There are good reasons for supposing that a former range occupied the site of the Alps at an early period, as the older strata show considerable folds. These ancient mountains were removed

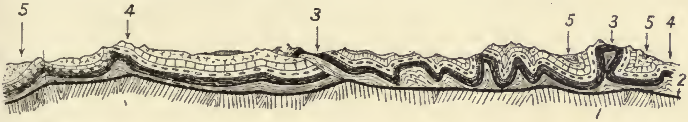

Fig. 49.—Section showing Carboniferous and Tertiary Folding and Denudations.—1, Gneiss. 2, Permian. 3, Lias. 4, Jurassic. 5, Tertiary. (A. Baxtorf, *Geol. Karte der Schweitz*, vol. xxi.)

by denudation, and the Permian and more recent strata were deposited upon the eroded surface. The Jurassic rocks were laid down in the ocean which transgressed the old land surface, and after a long period were thrust into folds and elevated high above sea level, which brought on the second glacial epoch, and the climate has remained severe in those high altitudes ever since. The heterogeneous Glacial Till which was heaped up by the ice forms the foundation of the Quaternary series of rocks, and is the next to be considered.

Repetition of Various Cycles.—The cyclic principles noticed in connection with the pre-Cambrian and Primary systems were thus repeated in Secondary and Tertiary times. The Cretaceous, Eocene, and Miocene sedimentary cycles were each followed by a volcanic episode and the pouring out of lava. Each period was closed by an upheaval of the earth's envelope, which brought on a period of glacial or aqueous denudation, according to the degree of uplift, and prepared the way for another sedimentary cycle. It is difficult, therefore, to over-estimate the important place that these interdependent cycles have played in the earth's architecture.

[1] James Park, "The Geol. of the Queenstown Subdivision." *Geol. Sur. New Zealand, Bull.* 7, 1909, p. 42.

[2] P. G. Morgan, "The Geol. of the Mikonui Subdivision." *Ibid., Bull.* 6, 1908, p. 35.

CHAPTER XXII.

THE QUATERNARY EPOCH.

Extent of Pre-Quaternary Ice Sheet—Some Effects of Glaciation—The Ice Plough and Cause of Motion—Great Volume of Glacial Till—Succession of Quaternary Rocks and Cause of Variation—The "Interglacial" Forest Epoch—One Premier "Interglacial" Epoch—Quaternary Interval of exceedingly Long Duration—Retreat of Ice Sheet during Epoch—Palæolithic Inhabitants of the Earth—Transition from Palæolithic to Neolithic Eras.

The area held within the grip of the Second icy envelope was not so extensive as that covered by the earlier one. Whereas the Permian rocks formed by the first glaciers are found in both Hemispheres, to within 20° of the Equator, the terminal moraines of the glaciers of the Great Ice Age extend little beyond the fortieth parallel of latitude, both north and south of that line. They may have extended further than this, but the direct evidence of their having done so is lacking, except in localities where the height of the mountains favoured glacial conditions.

Extent of Pre-Quaternary Ice Sheet.—The southern terminus of the glacial phenomena in North America runs across the whole of the continent from east to west. In the plains it recedes to the forty-sixth parallel of latitude, while upon the heights it advances southwards to the fortieth. In Europe the limits of maximum glaciation was confined within the forty-fifth parallel. South of the Equator the fortieth parallel passes through Cook Straits, which divide the North and South Island of New Zealand, and the Bass Strait between Australia and Tasmania. On the south side of this line glaciation was extreme; to the north it is almost entirely lacking. South Island, New Zealand, and Tasmania are excessively glaciated. The ice fringe skirted the coast of Australia only, to the north of the Bass Strait,[1] and also left the north of New Zealand almost untouched. Kerguelen Land in the Indian Ocean, on the fiftieth parallel, was buried under the ice sheet down to and even below sea level, and is glaciated from end to end.

The northern ice sheet seems to have been very irregular in its southern extension. While in North America the whole width of the continent north of the fortieth parallel was swathed in ice, only the north-western portion of Europe bears distinct evidence of glaciation performed at that time. "An area of about 4,000,000 square miles

[1] R. L. Jack and R. Etheridge, *Geol. of Queensland*, 1892, p. 620.

of North America and another of about 2,000,000 square miles in Europe, was covered by the ice sheets, which in their maximum extent had probably an average thickness of one-half to two-thirds of a mile, or perhaps even of a mile." Towards the central parts of the glaciated area a depth of 3 miles of ice is by no means improbable.[1] "The whole of Norway and Sweden has been moulded and rubbed and polished by one immense sheet of ice, which in its deeper portions could hardly have been less than 5,000 feet, or even 6,000 feet thick."[2]

Considerable differences of opinion exist as to the former extension of the glaciers beyond these limits of undoubted glaciation. There are, however, some traces of ice action in Lebanon and in Hermon, and gigantic boulder beds flank the northern escarpment of the Atlas Mountains.[3] The glacial history of the Roof of the World in Turkestan is in essential agreement with the American record in the main facts.[4] The glaciers of Mount Kenia "unquestionably extended for at least 5,400 feet below their present level."[5] These and other similar facts have led some geologists to believe that "during a late geological period land in the Northern Hemisphere was covered by thick crusts of ice, like ice in the Southern Hemisphere. The crust was continuous there down to low latitudes."[6]

If the northern ice did not extend into these areas, glaciers from local centres of accumulation produced rock grinding and striation, so that the climate was excessively severe over the whole globe. We may safely conclude that the main body of ice thinned out considerably from the centres and areas of maximum accumulation towards the lower and more temperate regions. "At this period the equatorial climate at the level of the sea was probably about the same with that now experienced at the height of from 5,000 to 6,000 feet, under the same latitude, or perhaps rather cooler."[7]

Some Effects of Glaciation.—Within these two areas, the evidence of glaciation is everywhere apparent. The higher peaks were ground down, smoothed, and mammillated, and hollows were carved out in the solid rock as the ice ploughed its way slowly down the valleys. The rounded appearance of many of the rocks has suggested the name of *roches moutonnées*, by which they are called. Where glaciers occupied the sites of lakes, the rounded rocks sometimes stand out of the water like "whale backs."

[1] G. F. Wright, *Ice Age in North Am.*, 1911, p. 503.

[2] James Geikie, *The Great Ice Age*, 3rd ed., 1894, p. 424.

[3] T. G. Bonney, *Ice Work: Past and Present*, 1896, p. 213.

[4] R. W. Pumpelly, *Exploration in Turkestan*, 1905, p. 200.

[5] Dr. J. W. Gregory, "The Glacial Geol. of Mt. Kenya." *Quart. Journ. Geol. Soc.*, vol. l., 1894, p. 530.

[6] J. F. Campbell, "Glaciation of Ireland." *Quart. Journ. Geol. Soc.*, vol. xxix., p. 219.

[7] Charles Darwin, *Origin of Species*, 6th ed., part 2, 1888, p. 164.

The sides of the valleys and summits of ridges within the glaciated areas were scratched, grooved, and striated by the grinding action of the ice. Along one side of the Llanberis Pass, on a precipitous slope, the striations run down the valley in the direction of the pass. Some of them are deeply graven, from two to 2½ feet wide, and 12 to 18 inches deep.[1] "So enduring is the gneiss of Norway and Sutherland, that even after the lapse of so long an interval, it retains its ice-worn aspect almost unimpaired, as if the work of the glaciers had been done only a few generations since."[2]

The same is true of the glaciated regions of Canada and the Rocky Mountains of Columbia. There is also abundant evidence that the glaciation of the South Island, New Zealand, in the Pleistocene, attained a degree of magnitude not exceeded in any part of the Northern Hemisphere. "The chains of glacial lakes, the ice-grooved and mammillated slopes of the mountains; (in places terraced to 6,000 feet and over), the perched erratics, the extensive rock striation, the widespread glacial till, all attest a period of intense refrigeration and prolonged glaciation."[3] "The features of the land in the Lake Whakatipu region, up to the height of 6,500 feet above sea level, are everywhere dominated by evidence of ice erosion, on a scale of magnificence that is unknown elsewhere in the Southern Hemisphere, and is perhaps without parallel outside the Polar regions."

The north vies with the south for premier place in this respect. "We must believe that all the hills and valleys were swathed in snow and ice, that the whole of Scotland was, at some distant date, buried beneath one immense *mer-de-glace*, through which peered only the highest mountain tops. This is no vague hypothesis or speculation based on uncertain data, no mere conjecture which the light of future discoveries may explode. The evidence is so clear and so overwhelmingly convincing that we cannot resist the inevitable conclusion."[4]

The Ice Plough and Cause of Motion.—In the frigid regions of the Northern and Southern Hemispheres, where the glaciers consolidated in extensive and massive sheets, the denudation was enormous. This was due to the slow but persistent movement of the ice plough, which was made a more effective agent of erosion by the mass of stones and boulders which it picked up on its way. This conclusion is based upon the fact that similar accumulations form a large part of the lower layer of ice in existing glaciers. In Greenland, it reaches a thickness of 50 to 70 feet from the bottom, and forms a shoe, which cuts and grinds itself into the rocks over which it

[1] Sir A. C. Ramsay, *Old Glaciers of Switzerland and Wales*, 1860, p. 44.
[2] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1903, p. 1359.
[3] James Park, "The Geol. of Queenstown Subdivision." *Geol. Sur. New Zealand, Bull.* 7, 1909, p. 4.
[4] James Geikie, *Earth Sculpture*, 1898, p. 176.

passes. In the same way, during the Glacial epoch, the more recent and less consolidated strata, besides much solid and metamorphosed rock, were carried from the high mountainous areas down into the valleys and hollows.

The explanation of the cause of glacier movement has led to much speculation amongst geologists and physicists. Tyndall supposed it to be due partly to sliding and partly to yielding of the mass. Croll concluded that the flow was caused by molecular changes due to the heat of the sun. Forbes' theory of ice plasticity is the one that now finds general acceptance. Glacier ice behaves somewhat after the fashion of a slightly viscous mass, and flows downwards under the influence of gravity, like a stream of lava. But since the maximum summer flow is four times the minimum winter flow, and the difference is greater at lower stations [1] exposed to more violent alterations of heat and cold, it is evident that the sun's action plays an important part in the process. The viscosity required by the Forbes' theory is induced by the change of seasons.

Great Volume of Glacial Till.—Whatever may be the true explanation of the ice flow, the extensive sheets of ice which held the Northern and Southern Hemispheres in their grip have long since retired from the greater portion of the area, and are now confined to relatively small limits. During the retreat, the rock-grinding process continually went on, and an immense volume of detrital matter was left lying upon the surface of the continents.

Figures can scarcely convey an adequate idea of the stupendous quantity of debris which was removed from the higher altitudes and deposited in the valleys. "The Delta of the Rhone, the Plains of Lombardy, Belgium, and Holland are built up in part of the materials from the top of the Alps." [2] Swedish and Finnish erratic material is spread over 1,250,000 square miles of Russia and North Germany. Were it transferred to the locality it originally occupied, the general level would be raised 250 feet.[3]

The total amount of drift in New England alone with its neighbouring terminal moraines has been set down as 750 cubic miles, or more than the mass of the White Mountains, and it has been estimated that 1,000,000 square miles of territory in North America is covered with glacial debris to an average depth of 50 feet.[4] In one subdivision of the New Zealand survey, "quite one-half of the lowlands is covered with morainic accumulation, which reaches a height of 1,000 feet." [5] In another area, the denudation of the land

[1] J. D. Forbes, *Travels in the Alps*, p. 129.

[2] Lord Avebury, *Scenery of England*, 3rd ed., 1904, p. 226.

[3] James Geikie, *Earth Sculpture*, 1898, p. 191.

[4] G. F. Wright, *Ice Age in North Am.*, 1911, pp. 259, 280.

[5] P. G. Morgan, "The Geol. of the Mikonui Subdivision." *Geol. Sur. New Zealand, Bull* 6, 1908, p. 35.

has been enormous, " wide stretches of Miocene strata have disappeared."

Succession of Quaternary Rocks and Cause of Variation.—The heterogeneous, unstratified heaps of Glacial Till, formed beneath the ice, or piled up in the form of terminal moraines by it, are the base of the Quaternary series of deposits. The succession of these beds generally follows a similar order. The melting of the glaciers gave birth to copious streams of water, which in passing over the Till re-assorted the surface sands and formed rudely stratified layers upon it. Above these sands in sheltered areas not affected by subsequent denudation there are remains of a widespread forest growth, which clothed the continents after the retirement of the glaciers. The forests which adorned the landscape in those far-off days were eventually overwhelmed, at the Post Quaternary phase of the glacial epoch, and were covered over by vast quantities of gravel, to which the name of Upper Boulder Drift has been given.

There is a considerable variation in the depth, area covered, and character of the composition of these Quaternary deposits in different localities. The cause of these variations may be attributed to the slow advance of the ice sheath, which, having reached its utmost limits, began to retire as the climate ameliorated. Beyond the furthest limit to which the glaciers advanced, there is no true ground or terminal moraine. The re-assorted drift may, however, have been carried beyond these limits by the sub-glacial streams. Following close in the wake of the retiring ice, the land became slowly covered with vegetation, which formed what is now the interglacial dirt bed. In one district the till formed by the retreating ice is overlain by a similar accumulation heaped up during its advance. In another the retiring glacier replaced the earlier till with its own. Where the forest growth took possession of the ground, earth with remains of the vegetation overlies the Till. Where there was no forest growth the upper Boulder Drift directly overlies the Glacial Till. In this way the stratigraphical sequence of these deposits is very variable.

Whereas the advent of the Great Ice Age and its partial retirement was slow, the evidence shows that the later glacial episode, after the intervening forest period, was comparatively rapid. It has also been ascertained that running water played a more important part in the last chapter of glacial history than in the previous one.

All these factors contribute to the variation in the distribution of the Till and Drift. The inequalities in level, as well as the differing age of the rocks over which the ice passed, were responsible for much of the variation in the composition of the beds.

The order already given represents a normal succession in an area where the retirement of the glaciers was followed by a growth of vegetation, and where the final phase of the glacial conditions left an overlying accumulation of Boulder Drift.

The description of the glacial beds of Permian times might be repeated for the Boulder Till. There is the same evidence of fluvio-glacial action following the severe glaciation. The ice rapidly melted, and boulder-laden streams flowed out from the margin. The coarse material was early deposited upon the higher bluffs, while the smaller fragments were carried far down the valleys, and frequently travelled several miles.[1] In this way the material was roughly assorted, and thins out locally from north to south, and corresponds with the Permian and Jurassic deposits.[2]

The "Interglacial" Forest Epoch.—The Quaternary vegetation which took possession of the boulder- and moraine-covered continents after the ice had receded differs little from the Forest bed of the Norfolk coast, which dates from the Pliocene. It was also almost identical with what grows in the same latitudes to-day. It contained pine, oak, plum, plane, alder, elm, fig, laurel, maple, walnut, birch, and hickory. Only one species found in the Forest Bed has disappeared from the British Isles.[3] Many of the wild flowers of to-day carpeted the ground. Buttercups, marsh marigold, chickweed, mares-tail, dock, sorrel, pondweed, sedge, and others then made their appearance.

The remains of these "Interglacial" or Quaternary forests, between the Lower Glacial Till and the Upper Boulder Drift, indicate that there has been no marked change of climate in this country since the close of the Ice Age down to the present time. The vegetation of the North American Interglacial era, where glaciation was more general, marks a climate much colder than at present.[4]

The fossil remains of the forests which adorned the moraines of the Interglacial period, and composed its landscapes, are extensively developed in the New and Old Worlds. At Craiglockhart Hill, an interglacial bed of sand was exposed from 1 to 3 feet thick, in which a great many tree roots were observed in the position in which they had grown. The sand rested on a mass of till, and was covered by another accumulation of Boulder clay. Another bed of clay, similarly covered, was full of roots and stems of common hazel, which had evidently grown *in situ* long before the Upper Drift was laid down. Hazel nuts were plentiful in the clay which occupied a basin-shaped hollow in the surface of the Lower Till.[5] These interglacial beds are not confined to any one district, but are found in every part of the country where they have been looked for, and it is reasonable to conclude that there were times when the great ice fields which covered the country receded so far at

[1] S. Calvin, "Geol. of Howard County." *Geol. Sur. Iowa,* vol. xiii., 1902, p. 68.

[2] J. A. Udden, "Geol. of Pottawattamie County." *Geol. Sur. Iowa,* vol. xi., 1900, p. 250.

[3] H. B. Woodward, *Geol. of Eng. and Wales,* 2nd ed., 1887, p. 473.

[4] G. F. Wright, *The Ice Age in North Am.,* 1911, p. 592.

[5] James Geikie, *The Great Ice Age,* 3rd ed., 1894, pp. 100, 101.

least as to uncover the lowland tracts and valleys, and permit the growth of a widespread vegetation.

This interglacial vegetation is usually overlain by the Boulder Drift; but, in some localities, it occupies exposed tracts, and has remained uncovered since the time it was overwhelmed. Amidst the blank desolation and sterility of the Lewis moorland, the trunks of full grown trees, consisting of oak, alder, birch, and especially Scotch fir, are seen. The bare islands of Orkney and Shetland have also at one time supported large trees, while on the mainland itself it is difficult to say what district has not waved with greenery. Oak trunks of large dimensions are buried, and occupy levels and positions which are now in the highest degree unfavourable to the growth of timber.

The Interglacial period on the Continent of Europe and in North America is represented by a similar forest growth. At Zürich the beds yield Swiss and Scotch fir (with trunks as thick as a man's body), mountain pine, larch, yew, birch, oak, plane, hazel, common reed, bulrush, and raspberry.[1]

One Premier "Interglacial" or Quaternary Epoch.—The confusion which prevails in these surface deposits, as well as the varying order in which they frequently lie, has led some geologists to conclude that there were several interglacial epochs. It is probable that the uplifts which brought on glacial conditions proceeded in successive stages, and that each upward movement caused an extension of the glaciers, and each interval was marked by retrocession. The Kansan and pre-Kansan tills of Iowa are separated by a forest bed epoch, which may mark such an interval, as they are both of early Quaternary age. After the elevation had reached its maximum and the ice had commenced its general retreat, a long period elapsed before the closing or Iowan Drift was spread out.

Mr. Wright thinks that the interval between the two leading epochs may be regarded as the chief Interglacial epoch.[2] The initial and final phases are more widely separated and more definitely marked than the several episodes of deglaciation. On this side of the Atlantic, we are advised meanwhile "to be content with the recognition of one great interglacial epoch."[3] This conclusion at the same time simplifies the subject, and enables us to readily grasp the full significance of the essential details of the problem.

Quaternary Epoch of exceedingly long Duration.—The deposits of till which were formed near the margin of the glaciers at the outset of the Quaternary era, when they commenced to melt, mark the first hour of interglacial time, and when compared with the drift, indicate the protracted duration of the epoch. The Kansan and pre-Kansan tills of Iowa represent a period of exceedingly great

[1] Sir A. Geikie, *Prehistoric Europe*, 1880, p. 76.
[2] G. F. Wright, *Ice Age in North Am.*, 1911, p. 439.
[3] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1903, p. 1315.

antiquity. The ancient land surface was oxidised to great depths by atmospheric action, and the pebbles are often decayed and sometimes wholly removed. The youthfulness of the materials of the Drift, on the other hand, is depicted in every feature. Its constituents are unchanged at the very top, and the boulders are as fresh almost as when they left their native place.[1] A moderate estimate would give the Quaternary epoch a duration of from ten to twenty times the whole of the historic period.

Retreat of Ice Sheet during Epoch.—As we have seen, the old glacial margin in North America approximates to the fortieth parallel of latitude; how far the ice sheath retired northwards during the protracted Quaternary period is difficult to determine. The suggested repetition of glacial phenomena point to a limited retreat, but other considerations suggest the contrary. It is probable that in higher altitudes, such as the Alpine region and the highlands of Canada, it was only partially dispersed; but in the lowlands melting was more rapid and extended far into northern latitudes.

Lake Winnipeg covered an enormously greater area in Quaternary times than it does now, and originally drained into the Mississippi valley towards the south. The ice sheets formed its northern boundary, and it received its water from them. The ice retreated northwards, and the Hudson Bay depression perhaps formed part of an extensive sheet of water, which was eventually drained away into the Atlantic as the ice retreated northwards. The mammoth is believed to have followed the ice front far into the Arctic circles,[2] but although it receded so far northwards, it was not entirely dispersed either from the Polar regions or from the greater centres of local accumulation, while glaciers extended downwards far into many of the deeper valleys throughout the Quaternary epoch. Remnants of this ice sheet remain even to-day beneath newer soils in sub-Arctic regions.

Palæolithic Inhabitants of the Earth.—The most important feature of the Interglacial epoch is the record of the human population which lived during the whole or portion of the time, and migrated into almost every quarter of the globe. The Quaternary or Interglacial age of geology is the Palæolithic era of Ethnology. The important place which man takes in the geological record is far in advance of his Eolithic predecessors. The gravels and river terraces of the Quaternary epoch abound in flint implements and weapons. Actual human remains, although comparatively rare, are not absent, and fragments of skeletons have been described which, with the implements, reveal considerable progress of intelligence and craftmanship during the period.

[1] T. E. Savage, "The Geol. of Tama County." *Geol. Sur. of Iowa*, vol. xiii., 1902, p. 241.

[2] G. F. Wright, *Ice Age, North America*, 1911, p. 437.

Some investigators have endeavoured to trace an advance of type or ascendant evolution, from the Pliocene through the various stages of the Quaternary epoch, but the number of human bones is so limited that what is looked upon as gradation by one is no more than variation to another. The subdivision of the epoch with the proposed classification of the associated human remains, is useful rather than marking a definite chronological sequence until further evidence is forthcoming. It is by no means certain whether Quaternary man existed throughout the whole of the epoch.

Palæolithic man occupied many countries, England, France, Spain, Italy, Egypt, Algeria, Somaliland, South Africa, Palestine, Madras, and other parts of India and North America. Darwin recorded the discovery of ancient relics in South America which

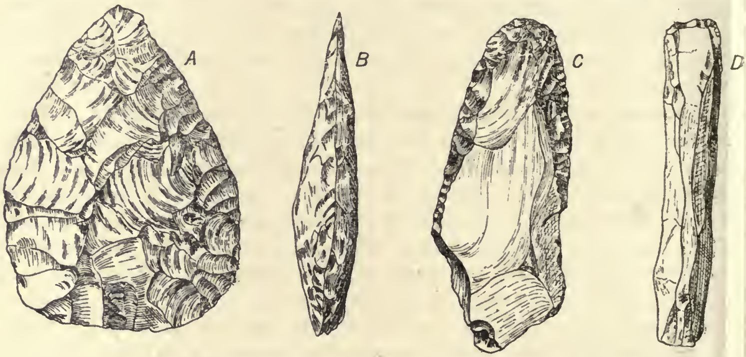

Fig. 50.—Palæolithic Flint Implements.—A, Hand axe. B, Edge of same. C, D, Scrapers.

appear to belong to the same period. "On the mainland, in front of San Lorenzo, beneath an extensive level plain, consisting of 100 feet of sand and gravel, numerous fragments of coarse red earthenware were discovered during the voyage of the *Beagle*."

Prof. Sollas has discussed the habits and occupations of the various Palæolithic races as far as they are revealed by the implements, weapons, utensils, drawings, and human remains which are preserved in various parts of the earth. He is of the opinion that they have descendants now living in the less civilised tribes, whose attainments and culture, art, and war are little in advance of the ancient stone age. He concludes that the Bushmen of South Africa, the Australian aborigines, the Esquimaux, and possibly the American Red Indians exhibit traits which indicate direct descent from different types of the Palæolithic inhabitants of our planet.[1]

Man was contemporaneous with a peculiarly diverse and remark-

[1] W. J. Sollas, *Ancient Hunters*, 1911, p. 382.

able group of animals, whose remains have an important place in the Quaternary fauna. The mammoth, hairy rhinoceros, hippopotamus, two species of elephant, lions, hyænas, cave bears, the musk ox, Irish elk, bison, reindeer, glutton, and others roamed the interglacial forests, or inhabited the swampy river valleys and marshy lowlands. Besides the flint implements which prove the presence of man at this time, occasional representations of some of these animals carved or scratched upon pieces of ivory or the antlers of deer have been preserved and recovered from the drift.

The Quaternary epoch was a prolonged and fertile era. The earth was clothed with rich and stately forests, herds of elephants marched with ponderous footstep through the jungles, hippopotamus and rhinoceros sought shelter in the swamps, and were preyed upon by the lion and hyæna. The reindeer, musk-sheep, and other more tender beasts were hunted by primitive man, who brought them to earth by well-directed blows from flint axe or spear. Choice portions found their way to the domestic quarters, and provided for the needs of wife and family.

Transition from Palæolithic to Neolithic Eras.—Looking forwards for a moment, there is a clear distinction between the Palæolithic races and those which succeeded them. There is a great time break in some parts of the world, and the Neolithic races seem to have lost some of the arts of their predecessors, who left "no traces of culture or equipment" behind them. Where relics of both Palæolithic and Neolithic man have come from the same cave, a layer of stalagmite sometimes covers the older soil, and forms a floor of the Neolithic era, as in Kent's cavern and Cheddar. This points to a period of enormous duration between one race and the next, and in the former instance there is no sign of transition from one to the other. The Neolithic remains first make their appearance after the deposition of the stalagmite floor.[1]

Prof. Boyd Dawkins says there is absolutely no connection between the Cave men and the Neolithic. The former had an extraordinary faculty in reproducing animal forms on their implements and ornaments. The latter had no idea of representing them.[2] The whole set of implements and weapons of the two periods are altogether different. Palæolithic ones were chiefly made of flint, and some of bone, and tools were adapted for use in the hand. The Neolithic craftsmen pressed basalt, quartzite, and sandstone into use, and fashioned his tools for use in hafts and shafts. The distinction also applies in America.

There seems to be a hard and fast line of demarcation between the races, and one age is marked off from the other, "not only by the very distinct character of its human relics, but also by the

[1] Sir J. Evans, *The Ancient Stone Implements of Gt. Bt.*, 2nd ed., 1897, p. 511.

[2] W. Boyd Dawkins, *Early Man in Britain*, 1880, p. 243.

strong dissimilarity of its mammalian remains."[1] Most of the ferocious animals of the Palæolithic period had disappeared in the Neolithic, and their place had been taken by less harmful species. The Newer fauna comprises a group essentially the same as those which now occupy Europe.

There was, at the same time, a great alteration in the configuration of the land surface, as well as in the animal kingdom, and opinion is sharply divided as to whether there was a cleavage in the human race or an evolutionary passage from one age to the other. Whether man survived the events which account for the physical and faunal changes is a vexed question, which will probably never be satisfactorily settled among geologists. The finds of flint implements enormously outnumber the human remains. A world-wide and perhaps dense population is practically lost to the geological record. Mr. Wright thinks that man shared in the sharp struggle which accompanied the new and rapidly changing conditions at the close of the Quaternary period. The evidence in Europe and elsewhere implies that the earlier races were largely exterminated, but to what extent is probably beyond demonstration.

It is reasonable to conclude that man did not entirely disappear, which would require a new creation, but that there is a connecting link somewhere between the races, although the facts already quoted point to so wide a difference between the habits and achievements of the respective peoples.

Flint implements of Palæolithic age are always found overlying the true glacial deposit, and underlying the higher level river gravels contemporaneous with the Drift, so that their place in the geological record is fixed within the confines of the Quaternary period. The final stage of the glacial activity and the deposition of sand, gravel, and clay, beneath or within which they, with human, animal, and plant remains are entombed, will form the subject of the next chapter.

[1] Sir A. Geikie, *Prehistoric Europe*, 1880, p. 23.
[2] J. N. Le Conte, *Elements of Geol.*, 5th ed., 1893, p. 636.

CHAPTER XXIII.

THE TILL AND DRIFT COMPARED.

Typical Distribution of the Drift—Structure of Till and Drift Compared—Condition of Stones Contrasted—Till and Drift compared with Underlying Rocks—Operating Causes different in Magnitude and Direction—Till and Drift with Relation to Physical Features—Erratic Boulders: their Large Size and Wide Distribution—Their Distribution compared with Till and Drift—All Phases of Drift long subsequent to Till—Running Water and Floating Ice associated with the Drift Epoch.

THE earlier Till of the Great Ice Age is as clearly of glacial origin as Permian Till or an Alpine moraine. The upper Boulder Drift and accompanying deposits which overlie the interglacial soils and remains of forest growth are, however, not so undoubtedly glacial in composition as the Lower Glacial Till and the Permian rocks. There is much difference of opinion regarding the mode of formation of these surface deposits, and they will consequently need full consideration.

The physical geography, as well as the geological structure of the Quaternary or Interglacial land surface, determined the local character of the upper Boulder Drift. In consequence of this, it varies considerably in different localities as much in outward form as in internal structure.

Typical Distribution of the Drift.—Over wide areas it is distributed in lenticular ridges, from a few hundred feet to a mile in length, from 25 to 200 feet high. These sinuous ridges have a persistent smoothness of outline and rounded tops,[1] and are known as kames, eskers or åsar, in the different countries where they have been observed. They are well developed in Scotland, Scandinavia, Ireland, and in New England. They reach their greatest development in Sweden, where they traverse the land as great embankments rising to a height of 50 to 100 feet above the general level, and following sinuous or river-like courses for distances of sometimes 150 miles or more.[2] They are met with at levels up to 1,000 feet. They were formed near the ancient centres of glacial dispersion, and seem to mark the beds of ancient watercourses. They are joined at their sides by others in the way in which a river is met by its tributaries,[3] and "are extremely common where large mountain valleys open out into a flat country."[4]

[1] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1893, p. 1342.
[2] James Geikie, *Earth Sculpture*, 1898, p. 196.
[3] A. de Lapparent, *Traité de Geol.*, 5th ed., 1906, p. 1667.
[4] A. H. Green, *Geol. for Students*, 1882, p. 633.

Once their direction has been marked out, they continue their course with a remarkable persistence over valley and hill. "Frequently, when following a kame down a gentle incline, or over a level plain, it will be found that in coming to a transverse valley, 100 to 200 feet deep and perhaps more, the kame is not interrupted, but descends into the valley on one side and ascends to the level of the plain on the other." [1] The Merrimack River bed is crossed by several lines of kames in this way. Followed further in their course, they develop into wide sandy plains many square miles in extent. They have their origin in the hilly uplands, and spend themselves in the low-lying flats.

Other phases of the closing epoch of the glacial era are represented by the loess, carse clays, river terraces, high-level gravels, and erratic blocks, but as there are important differences between the upper and lower boulder formations proper, which are of utmost importance in determining the mode of formation of the Drift, these associated phenomena will be considered in the next chapter, and our attention concentrated upon the distinctive features of the Till and the Drift.

Structure of Till and Drift Compared.—The structure of these accumulations is quite different. The lower Glacial Till is "a true land deposit, which has been formed as the bottom moraine of an old glacier mass." Such deposits due to land ice are practically unstratified (Plate X., Fig. 1). The moraine mounds piled up in this way "consist of the usual heterogeneous assemblage of angular blocks, stones, and clay derived from the hills above." [2]

The eskers, on the other hand, "are not infrequently distinctly stratified." [3] These ridges, known in Scotland as kames, in Ireland as eskers, and in Scandinavia as åsar, consist sometimes of coarse gravel or earthy detritus, but more especially of clean, well-stratified sand and gravel [4] (Plate X., Fig. 2), thus pointing to conditions of deposition "quite distinct to those under which ordinary boulder clay was accumulated." The ridges of lower boulder clay must not be confounded with those of the esker gravels, which are due to entirely different causes, and composed of different materials. [5]

Condition of Stones Contrasted.—The Lower Till, which is similar to the morainic matter found at the foot of modern glaciers, consists principally of sharply angular and sub-angular rubbish, mixed up with sand and clay. A good percentage of the included boulders are distinctly striated and little water worn. The stones are unlike those rounded by rivers or waves. Although some are well-rounded, others do not appear to have suffered notable wear. Characteristic

[1] G. F. Wright, *Ice Age in North America*, p. 350.
[2] Sir A. C. Ramsay, *Old Glaciers of Switzerland and Wales*, 1860, p. 68.
[3] T. G. Bonney, *Ice Work: Past and Present*, 1896, p. 204.
[4] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1893, p. 1323.
[5] E. Hull, *Phys. Geol. and Geog. of Ireland*, 2nd ed., 1891, p. 109.

Fig. 1.—Cross-bedded Sands and Gravels. Blackpool.

Photographed by R. Welch. *The Drift.*

Fig. 2.—Unstratified Till with Boulders at Base.

British Survey Photograph. *The Glacial Till.*

till stones have many faces, which are planed rather than worn. In the stratified Drift water-worn forms predominate. The many-sided, plane-faced stones are often altogether absent, and this applies to the large and small ones alike.[1] Striated stones are rare or absent. "That the gravels of the Upper Drift are not the ordinary moraines of glaciers, as some geologists have imagined, seems to be conclusively indicated by the absence of angular rubbish, by the well-worn and water-rolled character of the stones." [2]

Till and Drift compared with Underlying Rocks.—A comparison between the fragments in the lower till, and the rocks upon which it lies, shows that this deposit has been constructed out of these underlying rocks. "In the heart of the Silurian uplands we find the till crammed with fragments of Silurian rocks, soon after passing the boundary of the Silurian and Old Red Sandstone we notice that the boulders of the latter make their appearance, at first sparingly, and then rapidly increasing in numbers. Soon the colour of the till deepens into a red as pronounced as the Old Red Sandstone itself." [3] Roughly, the different types of till are confined to the outcrops of the various corresponding rocks, and sometimes the transition from one to the other is very abrupt.[4]

The principal mass of the detritus of the Russian Drift also is of local origin, and very clearly bespeaks the nature of the subjacent formations, whilst the great Northern Drift is perfectly independent of such subsoils, and has been distributed in zones or trainées which traverse the Silurian, Devonian, and Carboniferous regions. It became more diversified and added to as it passed southwards over those formations by deriving materials from each, and is made up of the ruins of them all.

Thus, although the materials of the Till have been moved some distance from their original resting place, they have not travelled far. The upper Drift, on the other hand, contains great quantities of travelled and well-rounded erratics, which have come from long distances. The parent rocks, whence they were derived, may be as much as 50 or 60 miles away, or even more.[5]

Operating Causes differ in Magnitude and Direction.—In North America "the earlier drift is widely and uniformly distributed. The phenomena of glacial erosion connected with it, although present, are feeble. The whole aspect of the deposit indicates an agency which spread the drift over the surface smoothly and relatively gently, with little forceful action. The later epoch, on

[1] R. D. Salisbury, *Glacial Geol. of New Jersey*, 1902, pp. 19, 20.
[2] Sir A. Geikie, *Scenery of Scotland*, 1901, pp. 311, 315.
[3] Sir A. Geikie, *Prehistoric Europe*, 1880, p. 187.
[4] C. T. Clough and Associates, "The Geol. of East Lothian," 1910, p. 171. *Mem. Geol. Sur. Scotland.*
[5] Sir R. I. Murchison, *Geol. of Russia and Ural*, 1845, p. 520.

the contrary, was characterised by strong glacial action. The vigorous action of the glaciers of the second epoch, and the rapid drainage in general, stand in marked contrast with the gentle action and imperfect drainage of the earlier epoch." [1]

Another important difference between the Till and the Drift is the direction sometimes taken by the lines of kames. They do not run in the same direction as the glaciers which preceded them. For instance, the Queenstown Esker lies nearly at right angles to the path of the glacier.[2] Besides this, the comparatively uniform size and bedded character of the material render it difficult to understand the conditions in which it was deposited. An instance is also recorded where the direction taken by a kame is from south-west to north-east, exactly opposite to the ice flow, which was from north-east to south-west.[3]

The retirement of the glaciers which heaped up the Lower Till took a northerly course. They were dispersed by the heat of the sun, and followed the direction of the ice sheet of Permian age. In Vermont, New Hampshire, Massachusetts, and Connecticut, beneath the drift, " the surface of the rock is grooved and furrowed in a generally southern direction, though varying with the contour and course of the valleys. The striations occur on the north side of mountains, but not on the south." [4] In Kerguelen Land, in the Southern Hemisphere, the ice retreated from north to south.[5] The esker gravels, on the other hand, were distributed from mountainous centres outwards in all directions.

Till and Drift with Relation to Physical Features.—" At greater heights than 300 feet above sea level, these remarkable ridges are, as a general rule, confined to the valleys, but at a lower level they seem to be tolerably independent of the present configuration of the ground." [6] Once their direction was determined by the highland valleys; it was not altered when the plains were reached. The direction of glacial motion, on the other hand, was generally north and south, and was rarely independent of physical features. It was modified and even checked by moderate obstacles, and was generally down the valleys.

The water-worn gravels and far-travelled boulders of the later Drift rose to heights never reached by the Till, and attained to the tops of the highest hills of the St. Lawrence valley, 1,200 feet in height,[7] and elsewhere, as we shall see, to still greater elevations. The Boulder Till was brought downwards from the highlands, and

[1] G. F. Wright, *Ice Age in North America*, 1911, p. 579.

[2] James Park, *Geol. Sur. New Zealand, Bull.* 7, p. 31.

[3] W. J. Sollas, " A Map to show the Distribution of Eskers in Ireland." *Sci. Trans. Royal Soc. Dublin*, vol. v., 1896, p. 793.

[4] S. A. Miller, *North American Geol.*, 1899, p. 86.

[5] R. L. Jack and R. Etheridge, *Geol. of Queensland*, 1892, p. 619.

[6] T. G. Bonney, *Ice Work: Past and Present*, 1896, p. 111.

[7] Sir J. W. Dawson, *Acadian Geol.*, 1891 (Sup. to 2nd ed.), p. 8.

remained there. The Drift was carried down and swept upwards again, and still remains at considerable altitudes.

Erratic Boulders: their Large Size and Wide Distribution.—The upper and lower accumulations are essentially different, therefore, in internal composition, in geographical distribution, and in mode of formation. These differences are equally apparent, when the erratic blocks associated with the upper deposits are considered. The erratic blocks, together with the widespread sheets, hummocks, and ridges of sand and gravel, form "the youngest of all the glacial deposits." They appear almost everywhere over the low grounds of North Europe. Sometimes, where the Upper boulder clay is not present, "it is replaced or represented by these large erratic blocks, which are then found strewn over the upper surface of the interglacial gravels."[1]

These perched blocks are a striking feature of the landscape of all glaciated countries, both in the North and Southern Hemispheres. Some of them are of enormous size and weight, and have been removed "far from their original home." The "Pierre de Crans," near Nyon, is 73 feet long and 25 feet high. "The Pierre a Bot," near Neufchâtel, is 62 feet long, 48 feet broad, and 40 feet high, and weighs 15,000 tons.[2] One of the largest in North Wales measures 24 feet × 18 feet × 9 feet. In Western Otago, New Zealand, there ? is a number of these huge fugitives. One in particular is 20 feet × 14 feet × 10 feet, and weighs 240 tons. A granite boulder, 680 tons in weight, rests on the slopes of the Hoosac Mountains, at least 1,000 feet above the valley. Boulders weighing as much as 8,000 and 9,000 tons are not uncommon, and a mass of Chalk, 3 miles long, 1,000 feet wide, and 100 to 200 feet thick, in Southern Sweden, bears testimony to the transporting power of the icebergs. A village on the East Coast of England has been built upon a similar transported boulder.

Large areas of the continents of the New and Old World are littered with these blocks of all dimensions. They are foreign to the localities in which they lie, and owe their present position to one and the same cause. In the vicinity of Pierre, U.S.A., Laurentian boulders, which in size sometimes attain a diameter of 4 to 5 feet, frequently almost cover the ground. From the German Ocean and Hamburg in the West of Europe to the White Sea in the North, a vast zone of country, having a length of 2,000 miles and a width of from 400 to 800 miles, is more or less covered with detritus, including erratic crystalline blocks of colossal size, the whole of which have been derived from the Scandinavian Chain.[3]

Distribution of Erratics compared with Drift and Till.—Erratic

[1] E. Hull, *Phys. Geol. and Geog. of Ireland*, 2nd ed., 1891, p. 119.
[2] E. F. H. Kayser, *Text-book of Comp. Geol.*, 1893, p. 378.
[3] Sir R. I. Murchison, *Geol. of Russia and Ural*, 1845, p. 507.

blocks sometimes lie upon the top of kames and eskers. "They are rarely bedded in the gravels, but are not infrequently found dotted over the tops and slopes of the hillocks, as if they had been dropped upon the surface." A little consideration will convince us that if a moderate size boulder lies loosely upon a mound of comparatively fine stratified gravel, both block and gravel cannot owe their present position to the same local cause. The force which was required to heap up the fine material would be unable to move the heavy erratic. The agency with sufficient energy to roll the erratic would obliterate the mound beneath. Moreover, if both gravel and boulder had been in motion at the same time, the large blocks would have found their way to the bottom, rather than remain perched upon the surface, as they are.

The lower Glacial Till is quite local in character, and has travelled only short distances, whereas some of these huge erratics have travelled as far as 600 to 700 miles from districts where they are native.[1] We see, then, that while the Till is of strictly local derivation, the Upper Drift is less and the erratic blocks the least local of the three phenomena.

The direction taken by the fugitive boulders during transportation was similar to the Kames. They are usually dispersed from mountainous centres outwards in all directions.[2] The Scandinavian fugitive erratics were dispersed eccentrically from the crystalline highlands of that country, and travelled great distances towards all points of the compass. Those in the Russian provinces generally decrease in size the farther they are away from the original source. In the neighbourhood of St. Petersburg they measure from 2 to 3 yards in circumference, but only as many feet at Moscow.[3] Their distribution was thus comparable with the eskers, which sometimes moved in an east and west direction, right across the path of the glaciers which eroded the lower Till, and even from south to north, or contrary to them.[4]

The accepted theory of glacial motion requires that it should flow from the colder heights down into the plains, like a viscous mass. The boulders of the Alpine glaciers seem always to descend.[5] This is observed to be true of the older Glacial Till,[6] because the lobes of the glaciers conformed more or less closely to pre-existing valleys.[7]

"Search the whole wide valleys from their source to their termination, and we shall not find a single example of a boulder clay (Till) stone which has travelled up the valley, and the same holds true of every region of Scotland."[8] The ice was conducted in its

[1, 2] G. F. Wright, *Ice Age in North America*, 1911, pp. 244, 246.

[3] Sir R. I. Murchison, *loc. cit.*, pp. 527-8.

[4, 5, 6] G. F. Wright, *Ice Age in North America*, 1911, pp. 187, 249, 401.

[7] J. H. Ogilvie, "Glacial Geol. in the Adirondacks." *Am. Journ. Geol.*, vol. x., 1902, p. 398.

[8] Sir A. Geikie, *Prehistoric Europe*, 1880, p. 187.

passage downwards by the sides of the hills, and even moderate ridges were effective in deflecting its course.

"From the evidence of the travelled boulders, on the other hand, the ice sheets moved in a direction which was quite independent of the form of hill and dale."[1] Shap granite erratics are observed to have travelled from the Wasdale Crag, over the limestone ridge of Orton, across the Vale of Eden, and the limestone peaks of Stainmoor, over the Oolite and Chalk ranges beyond the Vale of York, before they came to rest at Flamborough Head. The dispersal of the Boulder Drift and these erratics cannot, therefore, be attributed to the ordinary movements of land ice.

All Phases of Drift long subsequent to Till.—Sir J. W. Dawson has associated Terraces with the kames, and attributes them to the same cause. "The river terraces in Switzerland are in many cases, like the eskers, covered with erratics."[2] The only difference between the terraces, which occcupy such an important place in the American geological record, and the kames and eskers is probably due to topography. The former are confined to the greater river valleys, whereas the latter are only found in regions where drainage was limited, and where the local mountains seem to have played a controlling part in their initial formation. In the river valleys of Western Europe, the Loess, or brick earth, forms the upper bed of three distinct terraces, all of which are late Quaternary, so that it is apparently the last phase of the same cause which will explain the formation of the kames and eskers.

The Glacial Till, which marks the dawn of the Quaternary epoch, is a well-marked geological horizon. It was succeeded in many parts of the temperate zone by the interglacial forest era. The kames, terraces, erratic blocks, and loess, then, occupy another well-defined horizon. They are distinct in every way from the morainic Till, and separated from it by a wide time interval. The kames and other associated phenomena each represent a different phase of the Drift period, and are all due to the same widespread cause operating at the time of transition from the Quaternary to the Recent epoch.

Running Water and Floating Ice associated with the Drift Epoch.—It has been supposed by many writers that these ridges of sand and gravel are due to torrents of water, which, in escaping from the melting glaciers, rolled and re-assorted the surface of the moraines and ridged them up in the form of kames. Were this the case, we should expect to find that similar mounds of stratified sand and gravel are associated with the lower Till, which was formed at the earlier glacial retreat, as well as in connection with existing glaciers.

We have already seen that there is practically no evidence of

[1] E. Hull, *Phys. Geol. and Geog. of Ireland*, 1891, p. 253.
[2] James Croll, *Climate and Time*, 1885, p. 239.

such water action in the Till, and "nothing quite like true kames have been observed along the margins of the Greenland ice, where they have been diligently looked for." The Post-Quaternary phase of the glacial episode was unique. There is little if any correspondence between them and either the earlier or present glacial phenomena. Sir A. Geikie says that "it must be admitted that no wholly satisfactory explanation of the mode of their formation has yet been given."[1]

At the same time, they are in some way due to glacial dispersion, for the erratic and perched blocks are often striated. They were probably once incased in the lower portions of the ice, and formed part of the plough-shoe, or were transported upon the surface of glaciers until icebergs floated away from the main mass, carrying erratics with them.

The stratified character of the kames, the river-like courses they take, as well as the water-rolled pebbles of which they are so largely composed, show "that moving water must have been concerned in their production."[2] The perched blocks have been floated into their present position. "The loess is primarily a flood loam of glacial times."[3] Running water, therefore, played a more important part in the distribution of the various components of the Drift than it did in the Permian, or does where glaciers slowly melt in Alpine regions. This accounts for the wide and striking differences between the early and late Quaternary deposits pointed out in this chapter. A fuller discussion of the cause of these differences will form the subject of the next chapter.

[1] Sir A. Geikie, *Text-book of Geol.*, 1893, p. 1323.
[2] Sir A. Geikie, *Prehistoric Europe*, 1880, p. 311.
[3] Prof. J. Geikie, *Earth Sculpture*, 1898, p. 192.

CHAPTER XXIV.

THE LAST TRANSGRESSION.

Transgression not due to Depression of Continents—Transgression a Repetition of Earlier Ones—Definition of Ice Age—Identity of post-Quaternary Ice Age—General Sequence of Events—The Powerful Glacial Rivers—Initial Phase of Transgression—Attains Considerable Magnitude.

THE transgression at the close of the Quaternary period, which agrees in time with the conclusion of the Palæolithic epoch, is supposed by many geologists to have been one of many similar occurrences. It was due, they say, to a sinking of the earth's crust. Sir A. Geikie, on the other hand, has pointed out that " the many wide regions of the loess (whose deposition, as we have seen, was simultaneous with the kames, terraces, and erratic blocks), evidently pertain to one and the same period, and must owe their origin to the same widely-acting cause or causes. They occur in so many different regions that we are precluded from supposing that the elevation and depression of the land can have anything to do with their formation." [1]

Transgression not due to Depression of Continents.—Had the submergence been due to a depression of continents, we should expect to find marine silt strewn upon the land up to the highest level attained by the sea. On the contrary, the deposits contain the remains of a land fauna and fresh-water mollusca. If the surface drift is followed outwards from the highland centres, it becomes more and more water-worn. The coarse, irregular, angular, and striated boulders were evidently swept outwards by rapidly running water from old glaciated centres, and the corners were rounded and the scratches obliterated, until the stones were reduced to true shot gravel. The erratics and upper Boulder Drift took the same course, from the mountainous centres outwards towards the shores, and could not have been dispersed by marine flooding. Moreover, as the drift is tracked towards that direction it assumes a more or less marine character, which indicates that the level of the sea increased as the currents flowed over the land towards the ocean.

Professor James Geikie is very emphatic : he says, " I now hold that neither the erratics nor any part of the stratified and re-assorted upper drift of the interior offer any evidence in favour of marine submergence " ; but although the evidence of continental sag or

[1] Sir A. Geikie, *Prehistoric Europe*, p. 234.

depression is largely negatived by the facts, there are many points of resemblance between the last transgression and previous ones which point to the operation of similar causes. It is in the light afforded by these that we may hope to trace the genesis of the Post-Quaternary submergence. It is reasonable, therefore, to inquire if elevation of the earth's surface was not again the operating cause.

Transgression a Repetition of Earlier Ones.—Although the physical constitution of the earth precludes the former hypothesis, as do the facts, the latter theory is not inconsistent with a rigid envelope, and is fully in accordance with the facts. If the earth's crust is as rigid as some believe it to be, its spheroidal figure is strong to resist movements of depression. Local sinking of this nature is conceivable, but for all quarters of the globe to be depressed at the same time is quite unlikely. At many previous periods, however, elevatory movements have caused transgression, and, since the crust is less strong to resist force from within, it is reasonable to suppose that similar elevations may have had something to do with the cause of the submergence.

The phenomena associated with the close of the Quaternary age point to a repetition of the river erosion, which occurred during the Coal epoch. Similar ridges and beds of sand and gravel were built up, and river-like channels were cut down into the older rocks at both periods. If we consider the whole of the deposits from the close of the Mountain limestone age to the close of the Jurassic as marking a long period of transition, and compare them with the Tertiary and Quaternary, there is a remarkable similarity between them. Each period was denoted by the accumulation of mechanically-formed sediments, which take a more prominent place in the geological record than do the organic sediments. Each period was closed by marked fluviatile activity, and a great transgression of the oceans, which were made fresh by the acquisition of the fresh water. The concluding submergence of the Quaternary epoch seems to have been less in magnitude than the Great Transgression, and subsided more rapidly, as no organic sediment was laid down beneath it.

The Quaternary Submergence thus combines certain features of both the Cretaceous and Eocene Transgressions. The former was due to the final melting of the Permian ice sheath, and the latter to aqueous precipitation brought on by elevatory movements of the earth's crust. It is probable that similar causes were in operation at this time, and that they produced similar results. The submergence was a repetition of phenomena not uncommon at many earlier periods of the earth's history. It appears to have been partially due to the melting of the glaciers, as the majority of geologists think, together with undulatory movements of the earth's crust, which produced atmospheric condensation on something like

the same scale as similar disturbances had produced in the Coal epoch and in Tertiary times.

Definition of an Ice Age.—If, then, we gather up the evidence afforded by the various glacial episodes, including the Permian, the Great Ice Age, and the Post-Quaternary, we shall be in a position to define an ice age, and to explain much that is obscure in the phenomena associated with the last Transgression. In this way the past is of utmost value in supplying the solution of the more recent.

The succession of moderate uplifts in the Carboniferous epoch produced aqueous erosion. It was the final upheaval which was the cause of the accumulation of glacial *nevé.* The melting ice afterwards supplied the water which re-assorted the Permian Till and laid down the beds of fluvio-glacial sediments in the early Secondary. These three phases were duplicated in the Great Ice age. The Glacial Till is preceded by the Pliocene gravels and outwash plains of similar material, and is followed by fluvio-glacial gravels. These distinctions in both cases apply to the geographical distribution and to the stratigraphical relations of the deposits. The Permian and Pliocene gravels were principally developed beyond the ice margin, where rain fell instead of snow, but the till of both ages is often underlain by deposits of well-rounded pebbles and overlain by well-stratified sand with rounded boulders.

An ice age may, therefore, be defined as a succession of elevatory movements of the earth's crust, producing aqueous precipitation in the early and more moderate stages, and culminating in heavy falls of *nevé* as greater altitudes are reached. The extent of rainfall or snowfall is directly related to the degree of elevation, but is modified by the latitude at which the movements take place. When movement, and consequently ice accumulation, ceases, melting ensues until a portion or the whole of the *mer de glace* is dispersed, with the result that the sea transgresses the land in a greater or less extent, according to the area and depth of the ice, the rate of melting and re-evaporation of the water.

An ice age may consist of the first stage alone, or of all the phases in succession, according to local conditions, and the deposits laid down will vary for the same reason. They may even record with some degree of certainty the extent of elevation preceding the erosion. The finest silt or the coarsest glacial till may be produced, according to the moderate or excessive extent of the uplift.

Identity of Post-Quaternary Ice Age.—Before applying this definition to the Post-Quaternary glacial phase it is advisable to emphasise its identity, and nothing does this more certainly than the determination that it is widely separated in time from the "Great Ice Age." It might with reason be termed the Lesser Ice Age, to distinguish it from the earlier one. Compared with the pre-Quaternary glaciation, the Post-Quaternary was marked by a preponderance of the initial aqueous erosion and a much less

extended glacial phase. This accounts for the greater volume of the rivers of the period, and for the great differences in the character of the components of the Drift and Till which have been referred to.

The various phases of the Drift are perhaps nowhere so well represented as in the United States, and as they have been exhaustively studied we are able to follow the sequence of events very clearly. Separated from the Kansan Glacial Till and fluvio-glacial gravels by the wide interval of the Quaternary epoch, and lying upon a deeply eroded surface, are the Iowan loess and Drift. The Wisconsin gravels, or Upper stratified Drift proper, locally overlie the Iowan loess. Distributed alike over the Iowan and Wisconsin Drifts are the Erratic blocks, but whether their distribution over both phases of the Drift was contemporaneous is difficult to determine. But since the loess, drift, and erratics together mark the close of the Quaternary and the threshold of the Recent period, there is no wide time interval represented in them. A second addition of loam or clay similar to the loess is often in evidence above the Iowan loess and overlying the Drift.

General Sequence of Events.—According to the above definition, a portion at least of the Iowan loess marks the early phase of the Post-Quaternary Glacial episode, and consists of the finest dust derived from the leached surface of the more ancient Kansan Till by Quaternary winds. It was re-assorted during the erosion, which was a consequence of the more moderate earth movements, or directly washed out from the Till by the rains. This was followed by much stronger river erosion, when the drainage had much more freedom and the Wisconsin gravels were laid down. Glaciers then extended southwards and floated out upon the surface of the agitated and transgressing water, and deposited the huge erratics upon the newly formed surface of the loess and gravel trains. After this the clays and loams settled around them in the quieter water as the turmoil ceased. These clays take the place of the fluvio-glacial sands and silt of the earlier episodes. The later glaciers appear to have melted upon the surface of the sea instead of upon the land where they were formed. The evidence of ice movements upon durable rock is very limited at this time, although it is not entirely absent.[1]

There are other ways of interpreting the sequence of events, but the key to the situation is the aqueous erosion which preceded the glacial. A new and helpful factor is introduced by it. If it could be shown that there is a considerable time interval between the Iowan and Wisconsin stages, the former, with its erratics, and the latter, with the overlying erratics, may be the results of two final stages of the uplift, the later more marked than the earlier by strong river erosion. The method of reasoning would apply equally in one case or the other.

[1] R. Chalmers, "Surface Geol. of New Brunswick." *Geol. Sur. Canada Ann. Rep.*, 1885, pp. 32 g g.

The Powerful Glacial Rivers.—The Glacial rivers were then the cause of the initial erosion of the Post-Quaternary Ice Age, and their work is the first to receive consideration. The ancient weathered surface of the pre-Quaternary glacial moraines was deeply eroded. The denudation was developed partly by water which collected in gullies and ravines, and partly by broad sheets over wide surfaces.[1] The deep and wide valleys of the Pliocene age had been filled in with detritus from the glacial abrasion, and a small amount of trenching had been accomplished by the melting glaciers during the Quaternary period, but by far the greater portion of the erosion was occasioned immediately before the Iowan Drift was laid down.[2] Many river valleys in North America were filled with swollen torrents from 100 to 250 feet above their present level. They were not only wider and deeper, but were more numerous than those now included in the drainage system, as many have since been entirely deserted. Many were filled up with the sand and gravel carried by the currents, and existing streams have cut entirely new channels in the recent period, which sometimes cross and recross the old ones.

Some valleys have immense tongues of gravel at their entrance, extending out into the plains as if currents of enormous volume had swept through them from north to south. "Torrential rivers, great and tumultuous floods, and vast inundations"[3] occurred at the close of the Quaternary epoch. The pebble beds of the northern Drift of Shropshire formed at this period tell the same story as those at the base of the Trias in the same locality, as in both cases they came from long distances from the north. Mr. Jukes Browne thinks that the former must be regarded as the result of some very rapid and sudden change of climatic conditions, or of a season of unusually heavy rains, which produced floods of unusual magnitude.[4] M. de Lapparent concluded that the loess bears decided evidence of a regimè of diluvial rains having prevailed during certain phases of the Quaternary epoch. There was a particularly abundant atmospheric condensation. This rainy period was more general and equally significant as the earlier glacial episode.[5]

Initial Phase of Transgression.—The finest particles of wind-derived rock meal were the first to be carried by these torrents and deposited at long distances. As the currents increased in volume and vigour, coarser and heavier material was transported, but soon the seas began to transgress the land, and another change in the character of the deposits is noticeable. The stratification is more uniform and regular, and the material finer. The advance of the sea northwards over the recently deposited gravels produced an

[1, 2] S. Calvin, *Geol. Sur. of Iowa*, vol. v., p. 125; vol. vi., p. 449.

[3] Sir A. Geikie, *Prehistoric Europe*, 1880, pp. 54, 361; James Geikie, *The Great Ice Age*, 3rd ed., 1894, pp. 207-8.

[4] A. J. Jukes Browne, *Building of British Isles*, 1911, p. 216.

[5] A. de Lapparent, *Traité de Geol.*, 1906, p. 1699.

arrangement of beds comparable with the results of the Cretaceous transgression. The lower portion of the stratified Drift in New Jersey is composed of layers of gravel dipping rather steeply southwards while the upper are nearly horizontal.[1] The confused bedding of the lower part of some kames is in marked contrast to the exquisite stratification of the upper.

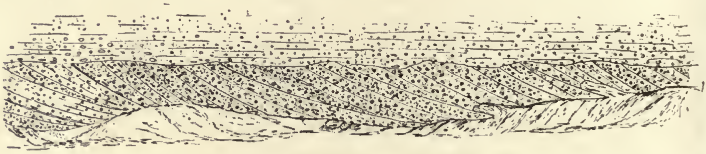

Fig. 51.—Cross-section of post-Quaternary Delta or Sand Plain. Horizontal Drift upon Steeply-inclined Drift. (R. D. Salisbury, *Glacial Geol. of New Jersey.*)

Attains Considerable Magnitude.—This transgression had attained considerable proportions during the deposition of the upper part of the Iowan Drift, as boulders were dropped into it during its formation by floating icebergs, when the water was over the top of the pre-existing bluffs, and deep enough to float them.[2] A similar depth of submergence is required for the distribution of the numerous and large erratics, which were brought from long distances and deposited upon the surface of the Iowan Drift and kames. In Ogle county, Illinois, "the evidence of floating icebergs and ice flows, with their freight of boulders and strong aqueous forces, are constant and recurring."[3] A considerable volume of fine silt was held in suspension in the water during the later stages of the submergence, which settled when currents had ceased and rest was restored. It now forms clays, loam, and loess, and lies at considerable altitudes, as well as upon the Iowan loess and kames in the lowlands. Fossil shells of northern origin are often found within these loams having been brought by Arctic currents, as was the case with the fauna deposited at the time of the pre-Cretaceous transgression. Sometimes they are heaped together in masses, and show signs of the currents which washed them about, while at others they appear to have lived in the position in which they now lie entombed.

This general outline will be supplemented by a consideration of the principal phenomena in detail, as it is impossible to discuss all the points of interest in a brief summary.

[1] R. D. Salisbury, *Glacial Geol. of New Jersey*, 1902, p. 624.

[2] H. Foster Bain, "Geol. of Woodbury County." *Geol. Sur. Iowa*, vol. v., 1895, p. 284.

[3] A. H. Worthen, *Econ. Geol. of Illinois*, vol. iii., 1882, p. 109.

[4] R. Chalmers, "Surface Geol. of New Brunswick." *Geol. Sur. Canada Ann. Rep.*, 1885, p. 4488.

CHAPTER XXV.

TRANSGRESSION AND PHASES OF DRIFT.

Formation of Drumlins—Formation of Kames and Flood Plains—Formation of Terraces—Formation of Transverse Kames and Lake Ridges—Formation of Kame Terraces—Distribution of Erratics—Accumulation of the Loess—The Quaternary Mammalia and the Submergence.

THE strong aqueous action which preceded the submergence, the transgression itself, and the subsidence of the water which followed, fully account for the formation of Drumlins and Kames, the stratification of the upper boulder Drift, the grinding of the angular debris into gravel, the formation of river terraces and carse clays, the distribution of erratics, and the accumulation of a portion at least of the loess. These various phases of the Drift will now be described separately.

Formation of Drumlins.—The old marginal moraines which originally stretched across the front of the glaciers were cut into by the strong currents which followed the direction of the glacier movement. The surface was first eroded and channels cut across the moraine, leaving ridges remaining. These ridges were further eroded, and their upper surface rounded. They were ultimately divided into sections by cross currents until only isolated hummocks of till remained, which are now called Drumlins. They are vast and shapely masses, steep at the sides and north ends, with the tops smooth and gently curved. The south ends gradually slope away. All of them are remarkably alike in shape, although they sometimes form isolated mounds or ridges 200 miles long, and trend in the same direction in one particular locality. The material which was swept out further to the north was heaped up to form kames, which occasionally lie upon the backs of the drumlins.

Observed effects of sheet flooding are an indication of the means whereby these mounds are formed. This takes place in regions subject to unusual precipitation, and where the gradient upon which hill-side freshets debouch are not too steep or too flat. The water is charged with silt, which is deposited in the form of elongated fans or deltas, when the flow ceases. These silts are again cut into by succeeding floods, and remnants of older fans sometimes remain to record the former strength of the freshets. These remnants sometimes stand out as low elliptical and circular mounds, which, after being modified and rounded, were half-buried by succeeding sheets of similar silt-laden water.[1]

[1] W. G. M'Gee, "Sheet Flood Erosion." *Bull. Geol. Soc. Am.*, vol. viii., 1897, p. 104.

Formation of Kames and Flood Plains.—The accumulation of the Iowan Loess preceded the Kames and should be considered first, but since the upper portion was laid down at a later stage the discussion of its origin will be postponed.

Kames or Eskers are of diverse origin. Prof. Sollas has reviewed the trend of thought regarding their derivation, and there is a consensus of opinion that they were built up by swift rivers in tunnels beneath glaciers, the melting of which supplied the water.[1] These rivers were of super- and sub-glacial origin, and carried vast volumes of debris, which is supposed to have been deposited within the tunnels, after the upper and lower streams had been united through the higher one encountering a crevasse and plunging down to the rocky surface below. This theory does not, however, meet many details of the case. While the rivers were confined to the ice caverns, which are supposed to have determined the rounded outline of the kames, the water would be running too swiftly for the gravel to find lodgment; erosion would take place rather than deposition under such circumstances, and indeed kettle holes and other phenomena attest this. It has also been further pointed out that kames broaden out further from their source to such an extent that the ice arches would have lacked sufficient support, and would probably have given way under their own weight. Moreover, although the glaciers of Post-Quaternary age were much less extended than those of the Great Ice Age, it is common for these gravel ridges to stretch away for miles beyond the terminal moraines of the earlier glaciers, where there was no ice to control their direction.[2] In some instances, also, the direction of kames is either directly contrary or at right angles to the ice movement.

One fact is, however, well established. They were originated by strong river currents, and in this they agree with other phases of the Wisconsin Drift, which was " water-laid from top to bottom."[3]

During the initial stages of this closing epoch " great currents swept down the valleys, carrying with them the angular debris. As this was hurried along, it was gradually rounded by attrition, and eventually passed into gravel." The boulder-laden torrents rushing down from the head of the valleys were met by the similarly laden streams flowing diagonally from the hills on either side. Where the currents clashed, the velocity of the water was checked, and a portion of the heavier material dropped. Sand and stone was in this way deposited in ridges along the lower slopes of valleys, though distinctly above their bottom, where the water had not too steep a gradient.[4] The currents swept the shingle over the mounds in

[1] W. J. Sollas, " A Map to show Distribution of Eskers in Ireland." *Sci. Trans. Royal Soc. Dublin*, vol. v., 1896, p. 791.

[2, 4] R. D. Salisbury, *Glacial Geol. of New Jersey*, 1902, pp. 137, 748.

[3] T. H. Macbride, " Geol. of Clay and O'Brien Counties." *Geol. Sur. Iowa*, vol. xi., 1900, p. 484.

sheets, and some were thrown backwards and forwards by opposing eddies.[1] Mounds were thrown up, only to be swept away again as the direction of the currents changed. The torrents hurried onwards into the lowlands, building up the eskers as they went, until they died out in the rising oceans beyond, where the gravel and sand were deposited in stratified deltas and "sand plains." [2]

Drumlins and kames were formed simultaneously, and the environment of their modelling was identical.[3] They are the results of contemporaneous erosion and deposition. Drumlins were carved out of ancient moraines, and the kames built up of the materials thus derived by the same currents.

The debris picked up in this way was sometimes transported for great distances, and the further it was carried from the source the more water-worn is its appearance. "A complete suite of gradation from typical till to completely assorted stratified drift may be observed, and the attrition of the materials presents a like gradation." [4] Southwards, the kame systems grade into gravel or åsar-plains. Near the kames the ingredients consist of coarse gravel, and as the plains decline southwards the cobbles decrease in size from 3 to 4 inches to coarse sand with small pebbles. "Proofs are abundant and overwhelming that the average shape of the gravel composing these plains shows immensely more water wear than the gravel of existing rivers." [5]

These flood plains are sometimes far inland and high above sea level, but their peculiar construction appears to prove the existence of a body of water into which the material was discharged, at least during the later stages of construction. The stratified gravels slope forwards at an angle of 25° to 30° to the south-west in much the same way that the post-glacial sands of the Trias were laid down in England. These sand plains are, upon a grander scale, comparable with the elongated deltas and fans of silt with occasional pebbles, which are formed by sheet flooding.[6]

Although large quantities of detritus were accumulated in the form of kames and åsar-plains, the larger portion is distributed in the lowlands, along watercourses and within depressions where, although it fails to comply strictly with the laws governing river deposits, its distribution is necessarily the result of laws governing the flow of water.[7] The valley trains were built up by rapidly

[1] A. H. Green, *Geol. for Students*, 1882, p. 663.

[2] W. H. Davies, "Glacial Sand Plains." *Geol. Sur. Canada Ann. Rep.*, 1885, p. 196.

[3, 4] T. C. Chamberlain, "The Horizon of Drumlins, Osar, and Kame Formation." *Am. Journ. Geol.*, 1893, pp. 264, 265.

[5] G. H. Stone, "Glacial Gravels of Maine." *U.S. Geol. Sur., Mono.* xxxiv., 1889, p. 441.

[6] A. P. Brigham, "Glacial Flood Deposits in Chenango Valley." *Bull. Geol. Soc. Am.*, vol. viii., 1897, p. 24.

[7] R. D. Salisbury, *Glacial Geol. of New Jersey*, 1902, p. 125.

running water carrying vast loads of detritus, and the coarser material was dropped nearest the source and the finer at a distance from it.[1] Where the stratified (Wisconsin) Drift fills the valleys it is several times as thick as in the uplands, and its surface is level-topped.[2]

Formation of Terraces.—The swollen rivers which occupied many channels that are now deserted, and filled many existing ones to such high levels and distributed the Drift in the lowlands, have left records which testify to the large volume of water which coursed through the valleys at this time. The coarseness of the material they carried bears witness to the volume of the currents,[3] and there is much evidence to show that numerous new channels were eroded " all at once and with great rapidity." [4]

Where valleys were large enough to cope with the unusual volumes of water which surged down them, high level terraces were deposited in the less agitated water along the fringes of the streams. The materials of which they were composed were " derived from the moraines left during the glacial period, fragments of which are seen to emerge from the alluvium." [5] The terraces are contemporaneous with the kames, and are due to similar causes. They were laid down upon the banks of broad lowland valleys, while the kames were heaped up along narrower ones in the highlands where the currents were stronger.

Formation of Transverse Kames and Lake Ridges.—Where the sheets of water, as they spread out in the plains beyond, met the rising waters of the ocean, a bar was thrown up, such as is formed at the mouth of large rivers, where the current meets the tide. At the point of collision the water was comparatively quiet, and the shingle held in suspension was released, and formed transverse banks of mud and sand. The kame along the Yorkshire coast at Flamborough Head was probably formed in this way, as were similar ridges parallel with the Atlantic coast in Maine and New Jersey. The material of which they are composed was also derived from beds of till of the vicinity, and it has been remodelled by the combined action of fluviatile and marine currents along the coast in much the same way that the lower Cretaceous conglomerates of the Indian and African Coasts were formed. The laden currents came from the land, and the material was worked over by the sea after it had been deposited upon the shore.[6] Similar " Lake Ridges " were formed round the Great Lakes, and now follow the contours

[1] R. D. Salisbury, *Glacial Geol. New Jersey*, 1902, p. 144.

[2] F. Leverett, " Glacial Formations, etc., in Eric and Ohio." *U.S. Geol. Sur., Mono.* xli., 1902, p. 332.

[3] G. F. Wright, *Ice Age in North America*, 1911, p. 322.

[4] H. F. Bain, " Geol. of Polk County." *Geol. Sur. Iowa*, vol. vii., 1896, p. 283.

[5] Sir A. Geikie, *Prehistoric Europe*, 1880, p. 396. R. Chalmers, " Surface Geol. of New Brunswick." *Geol. Sur. Canada Ann. Rep.*, 1885, p. 40 g g.

[6] R. Chalmers, " Surface Geol. of New Brunswick." *Geol. Sur. Canada Ann. Rep.*, 1885, p. 41 g g.

of the lakes, but at higher levels. They sometimes merge into river terraces, and are of the same age.

Formation of Kame Terraces.—Somewhat distinct from the high level terraces and ordinary kames, although allied to both, are the kame terraces. They are distributed along one or both sides of certain old Quaternary valleys, and are neither so continuous nor so uniformly related to the present river gradient as the ordinary terraces. The stagnating valley glaciers, which remained unmelted since the Great Ice Age, and extended down many valleys, formed the bed of the Post-Quaternary rivers which flowed over them.[1] Like modern glaciers, the ice was higher in the centre, so that the water was deeper on either side between the sloping bank of the valley and face of the glacier. As the silt-laden currents coursed down these side channels the detritus was captured in the pockets and other irregularities, so that when the ice was finally dispersed long after the rivers had ceased to flow, irregular terraces remained clinging to the gentle sloping sides of the bluffs. Contemporaneous erosion was also effected by these streams, so that a series of kame terraces may alternate with short stretches of elevated cutting in the valley sides, called hanging valleys.

Distribution of Erratics.—Slowly the ocean level was raised, and masses of ice floated out upon its surface. As the sea level rose higher the remaining glaciers were lifted off their bed and carried outwards by the turbulent currents. When the maximum height was reached, the water supported large numbers of icebergs upon its surface. They slowly melted and gave up their burdens, which sank and were deposited upon the submerged continents in considerable confusion, and sometimes upon the recently formed kames,[2] where many of them still remain to record the events. It seems that there is no other way of explaining how these enormous blocks were lifted from the valleys and carried over the adjacent heights, or how the fugitives have travelled so far over mountain crest and valley alike. The " mingling and crossing " of some of the erratics, which is so strange a feature of the dispersion, is also accounted for. The ice rafts were dispersed by the currents, then floated over the crests at the height of the submergence, their course being modified by the ridges beneath ; some went in one direction and some in another. The majority took the direction of the initial flow of the currents, and generally followed the course of the kames.

The peculiarities of the distribution of these fugitive boulders of distant origin are such that it could not have been accomplished by land ice. It has already been pointed out that they have been lifted to great altitudes above the rock systems, whence they are derived, whereas glaciers almost invariably move down valleys. The topography of the land surface upon which they repose should

[1] R. D. Salisbury, *Glacial Geol. New Jersey*, 1902, p. 121.

[2] *Ibid.*, p. 594.

show evidence of glaciation if they were transported in this way, but this is rarely if ever the case. In Iowa there is a column of limestone, 8 feet in diameter, projecting through the drift and surrounded by boulders.[1] It is difficult to see how this pinnacle could have escaped destruction if ground ice had over-ridden it.

Accumulation of the Loess.—The opinion of geologists is somewhat divided concerning the derivation of the loess. Prof. Wright has only recently said that the solution of its origin seems to be as far distant as ever. The impotence of science before this formation is to be deplored. Some think that it was partially, but not wholly, wind borne or of æolian origin, while others suppose that running water was the principal agent of its accumulation. "Probably no one questions the view that the influence of the wind has been important, and nearly all will concede that water, or at least imperfect drainage, has been influential. Thus division of opinion is concerned with the relative importance of wind and water in the distribution of the loess." [2] This general statement would be of much greater scientific value if it were supported by a definite apportionment of the loess into wind-borne and water-borne sections, but this does not seem to have yet been accomplished. If, however, we take into consideration the events which both preceded and accompanied its formation, together with the fact that the Iowan loess is separable from the Mississippian by the Wisconsin gravels, and is the first of the Post-Quaternary deposits, we have a basis for a possible distinction between the two kinds. It is quite impossible, however, to come to any conclusion without taking contemporary phenomena into account.

The exceedingly protracted duration of the Quaternary era and the character of its climate are of first importance in this respect. Atmospheric conditions were comparable with the Triassic, and were remarkable for excessive aridity on account of the abstraction of the moisture from the air by precipitation at the dawn of the Great Ice Age. Seasons of exceptional aridity and intense cold acted with strong effect upon the rocks that were not protected by the retreating glaciers. The frost disintegrated the surface, and the fine material was swept away by the piercing winds, and it may be supposed that this continued throughout the whole of the epoch, and when the glaciers had retired northwards the newly formed Till was subjected to similar decay, and contributed not a little to the storms of dust which swept across the Quaternary plains. In fact, wind-polished boulders have been discovered standing out of the till surface beneath the loess. The upper sides are completely and beautifully polished, but underneath they have been untouched,

[1] S. Calvin, "Geol. of Jones County." *Geol. Sur. of Iowa*, vol. v., 1895. p. 87.

[2] F. Leverett, "Glacial Formations, Erie and Ohio." *U.S. Geol. Sur.*, *Mono.* xli., 1902, p. 299.

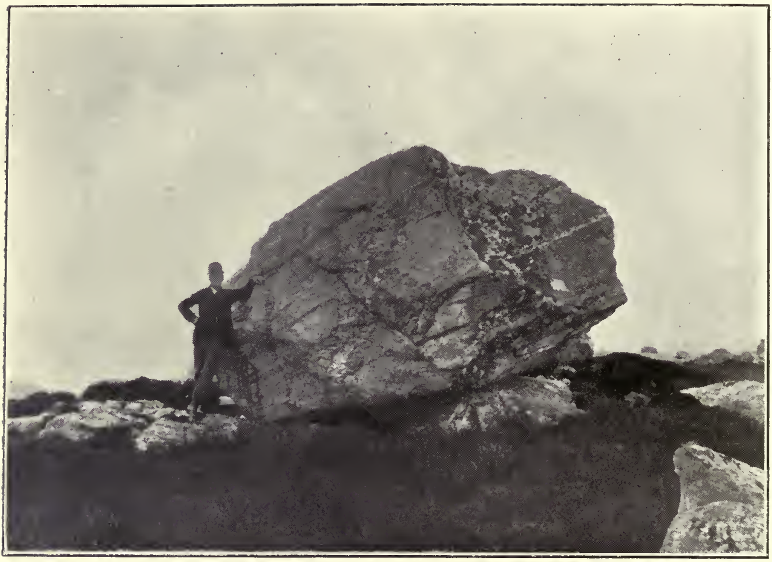

Fig. 1.—Perched Erratic.

British Survey Photograph.

Fig. 2.—The Loess of China.

Bailey Willis, "Research in China.

where they are embedded in the till.[1] As the era advanced, large volumes of dust were accumulated in localities favourable to deposition.

How far these deposits of wind-laid rock meal and sand particles remained undisturbed by the post-Quaternary erosion is not recorded, and it is probable that they gradually merge into a similar water-laid loess derived from similar sources by the moderate rains of the early stages of that period of erosion. The Kansan Till is, however, sometimes overlain by two distinct loess formations; one bluish-grey and older, the other yellow and younger. They are evidently related to the Kansan and Iowan Till respectively. The difference between them is very distinct, and a large part of the latter was probably carried for long distances, and is, as a rule, coarser than the older,[2] which is quite in accordance with the suggestion that the earlier loess is wind-borne and the newer water-borne. If the whole of the loess is of æolian derivation, which is highly improbable, it is overlain by the Wisconsin drift during the formation of which rivers and their tributaries were flooded and the torrential floods were loaded with detritus.[3] Kames composed of waterlaid gravels, high above the river valleys, gravel trains, river terraces, and outwash plains of stratified sand and gravel were laid down.[4] The Quaternary aridity was consequently succeeded by greater humidity and heavy rains were prevalent. It soon becomes evident that water displaced the wind as the active agency.

The Iowan Drift and a portion at least of the loess are of the same age,[5] and are remarkable for the contrast in the size of the included sand particles. The loess is composed of fine particles of rock flour, while the Iowan boulders are often 20 feet in diameter, 6 to 8 feet being a common size. The drift sheet is sometimes composed of these extremes, without the usual grading from one to the other. This comparison is illustrated in Plate XI., Figs. 1 and 2. Wind is, of course, out of the question as the transporting agent of these erratics. They are embedded in the loam in the same way that similar large boulders are associated with fine silt in the Carboniferous rocks of New South Wales.[6] There appears to be no question that the latter were released from floating icebergs, so that it appears equally certain that the later ones were also dropped by similar means into the submerged loess.

[1] F. A. Wilder, "Geol. of Lyon and Sioux Counties." *Geol. Sur. Iowa*, vol. x., 1899, p. 121.

[2] B. Shimech, "The Pliestocene of Sioux Falls." *Bull. Geol. Soc. Am.*, vol. xxiii., 1902, pp. 148, 153.

[3, 5] H. F. Bain, "Geol. of Guthrie County." *Geol. Sur. Iowa*, vol. vii., 1896, pp. 216, 462.

[4] H. F. Bain "Geol. of Polk County." *Geol. Sur. Iowa*, vol. vii., 1896, pp. 345, 350. S. Calvin and H. F. Bain, "Geol. of Dubuque County." *Geol. Sur. Iowa*, vol. x., 1899, pp. 472, 473, 474.

[6] See *Ante*, ch. xiv., p. 138.

At some time between the early and imperfect drainage and the floating of these icebergs, the strong erosion of the Kame and Terrace epoch took place. It was the fine particles of rock meal suspended in the water during the submergence which formed the upper loess and Leda clays after it had settled. These clays are often stratified and lie at high altitudes.[1] They sometimes contain Arctic and sub-Arctic marine shells, and were laid down in standing water,[2] and are not of æolian origin.[3] Clay and loam of the Champlain submergence occur hundreds of times overlying the kames and the last glacial gravels. Similar deposits exist all round the coast of Scotland, Scandinavia, New Jersey, and New Brunswick, and many other localities up to 800 feet above sea level. They are the final deposits of the Last Transgression, and are contemporaneous with a portion of the loess.

This interpretation of the problem of the loess is based upon the American sequence. There is also a very wide development of loess in China, where it has come under the observation and investigation of Prof. Willis. No attempt has apparently been made to separate the early and later phases of it, but there is the same indecision regarding its æolian or aqueous origin. The following remarks refer to what is probably the concluding deposit, in which no doubt a considerable proportion of originally wind-derived dust has been re-assorted and incorporated with the water-borne silt. Since its deposition, the loess of China has been exposed to the Siberian winds,[4] and has no doubt to some extent been affected by them, so that æolian deposition has been active in the initial and final stages.

Prof. Willis has pointed out that the loess of China sometimes occupies positions subject to scour, and unfavourable to accumulation, which precludes the æolian origin.[5] He also states that frequent and irregular layers of gravel occur at the base in such intimate association with the loess that it can only be ascribed to one agent—namely, torrential water. It is "the flour of the glacial mill," and owes its distribution to the turbulent water of the kame and terrace stage, which held the finest land-derived material in suspension while in so agitated a state. All the vegetable matter floated upon the surface, so that it now contains no remains of this character.

It was the large quantity of fine mineral matter held in suspension in the water as it retreated that led to the formation of the later loess. During the retirement of the sea this sediment settled down upon the land in the form of loam. While in this state it flowed

[1, 3] R. D. Salisbury, *Glacial Geol. of New Jersey*, pp. 209, 213.

[2] R. Chalmers, "Surface Geol. New Brunswick." *Geol. Sur. Canada Ann. Rep.*, 1885, p. 44 g g.

[4] G. F. Wright, "Origin and Distribution of the Loess in N. China and Central Asia." *Bull. Geol. Soc. Am.*, vol. xiii., 1902, p. 138.

[5] Bailey Willis, *Research in China*, vol. i., part 1, 1907, p. 193.

like a viscous fluid, and found its way into the deeper valleys and basins. After the water had disappeared it continued to flow onwards towards the coast at a decreasing rate, to form rich plains and deltas of the greater rivers, such as the Danube, Yangtse, Amazon, and Mississippi. The flow of the loess itself accounts for its comparative lack of stratification.

The sodden loamy mass settled as a mantle, over hill and dale, but is more typically represented in the greater valleys, into which it slowly followed the retreating water. The semi-liquid material spread itself out, and formed plains towards the mouths of the rivers. It shades away from the bluffs bordering the rivers, where it is coarsest, into the finer material in the lower flats. It has sometimes a vertical range of 1,000 feet in 20 miles,[1] and often gives a sweeping concave surface to the valleys in which it lies. Where the valleys grow steeper and at higher levels the upper surface is at a tangent to the rocky slopes of the hills.[2] These features indicate its subsidence upon the uneven surface of the land.

The Quaternary Mammalia and the Submergence.—There appears to have been abundant facility for the free migration of the land mammalia throughout the Quaternary epoch. North America, Europe, India, Asia, and even Australia were tenanted by large numbers of species, which have already been enumerated. The remarkable dissimilarity between them and more recent types, as well as their somewhat remarkable disappearance, suggests that the post-Quaternary glacial episode was fatal to large numbers of them. In fact, in America, their complete extermination at this time is one of the most remarkable facts of the geological record.[3]

In many parts of Europe the Pliocene pebble beds form the base of the more recent deposits in the river valleys outside the regions of former glaciation, the evidence of which is necessarily lacking there. Above the Pliocene and beneath the loess, there are two distinct terraces, each of which commences with the same base gravel, with the same fauna containing *Elephas antiquus*, higher up the angular sand, and the same heavy sand mixed with fauna of *Elephas antiquus* and Mammoth, and the same clay above them. These two terraces are approximately of the same age, and those who know them best attribute them to the very last sediments laid down by the torrents which established the transition between the Quaternary and Modern periods.[4]

It is a much debated-question whether the changes which overtook the Quaternary fauna and flora at the time when these terraces were formed, were due to rivers running at ordinary levels or at

[1] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1903, p. 1339.

[2] Bailey Willis, *Research in China*, vol. i., part 1, 1907, p. 194.

[3] G. F. Wright, *Ice Age in North America*, 1911, p. 706.

[4] M. A. Rutot, "Revision stratigraphique des ossements humains Quaternaires de l'Europe." *Bull. Soc. Belge et Belgique*, vol. xxvi., 1910, p. 155.

higher levels. Prof. Boyd Dawkins has, however, shown that the Quaternary terraces occur at various heights, both above and below the present levels of the rivers in the same valleys, which proves their greater volume.[1] Sir J. Evans says it seems impossible to do otherwise than attribute these beds to rivers flowing at much higher levels and more torrential in character than at the present day.[2] Their stratigraphical position beneath the loess clearly includes them in the early phase of the denudation which preceded the submergence. They are of the same age as the kames, so that the Quaternary fauna was evidently involved in those inundations, which mark the close of the Quaternary epoch.

"From the frozen sedimentary deposits that overlie the fossil ice in Siberia carcases of mammoth have been obtained, sometimes with the flesh still perfectly preserved." The remarkable preservation is an evidence of rapid entombment. The monsters are representatives of the Quaternary mammalia, and were overwhelmed by the transgression, floated into their present position, and upon the retirement of the water were frozen into beds of loam, in which they had become engulfed.

The post-Tertiary mammalian remains of Queensland are recovered from estuarian deposits containing recent shells. They usually bear evidence of having been drifted and water-worn, and are fragmentary.[3] They appear to have been totally destroyed by much the same means as those in the Northern Hemisphere.

In this extinction of the fauna at this time there is one more point of resemblance between the effects of the post-Quaternary and mid-Cretaceous transgressions. The Quaternary mammalia disappeared from the geological record in much the same way that the Jurassic reptilia were removed during the period of denudation which immediately preceded the rise of the oceans. In each case the remains are often fragmentary, and bear evidence of the destructive agencies.

[1] W. Boyd Dawkins, *Early Man in Britain*, 1880, p. 265.
[2] Sir J. Evans, *The Ancient Stone Implements of Gt. Bt.*, 2nd ed., 1897, p. 696.
[3] R. L. Jack and R. Etheridge, *Geol. of Queensland*, 1892, pp. 607, 608.

CHAPTER XXVI.

TRANSGRESSION: GENERAL.

America—Europe—Asia—Africa—Australia—New Zealand—Height and Duration of Submergence—Quaternary and Recent Denudation Compared—Earth still Growing—Conclusion.

THE following facts relating to the general extent of the post-Quaternary phenomena are to be taken as supplementary to those already considered. Its wide geographical range is also supported by the details attesting its magnitude.

The various features of the last important events of the earth's geological history are found in every country: in America, Africa, Europe, Asia, Australia, and New Zealand. The Boulder Drift, position of the erratics, terraces, and high-level gravels present modifications which are relative to the particular physical geography of the locality where they are found. The loess is the most widely distributed of all the deposits of the period, and occupies much of the highlands, but is principally developed in the lowlands. Mountainous centres have their outlying systems of kames and distribution of erratics. Valley systems have their terraces and loess.

America.—The period of floods and submergence is termed the Champlain epoch by American geologists. It was the period during which the drumlins and kames were accumulated there.[1] The earlier part of the epoch is marked by "the bold and crested height and deep cañons of the Rocky Mountain region, and in the deeply-cut gorges over a large part of the land. Later in the period transportation and deposition were the chief work of the rivers." [2] The stratification of the deposits varies from the most regular and that of gently moving waters to that formed under a vast and simultaneous supply of gravel, sand, and water. The flow and plunge style of deposition, which is due to rapidly moving water, charged with a large supply of sand, is common.

The material carried by the rivers was eroded and carved out of solid strata by the strong action of running water, and now forms rich alluvial plains. The Colorado River has, within a very recent geological period, dug out a valley more than 200 miles long, from 5 to 12 miles wide, and from 5,000 to 6,000 feet deep.[3] The vertical cliffs, needles, and even veritable obelisks, which rise up

[1] Warren Upham, "Drumlins and Marginal Moraines of Ice Sheets." *Bull. Geol. Soc. Am.*, vol. vii., 1895, p. 26.

[2] J. D. Dana, *Manual of Geol.*, 4th ed., 1896, p. 989.

[3] James Geikie, *Earth Sculpture*, 1898, p. 53.

in every direction, were cut out by the powerful erosion of the Quaternary rains.[1] The erosion of these gorges was commenced in the Pliocene era, received a great impetus in the Champlain epoch, at the close of the Quaternary,[2] and has continued in a minor degree down to the present time.

Evidences of the transgression in North America are frequent and recurring. There are marine beaches east and west of the St. Laurence River valley 1,000 feet high, and scattered erratic blocks from 500 to 1,200 feet above sea level.[3] Terraces at similar high levels with marine shells at 700 feet have been traced as far west as Lake Superior, and at even higher levels in Ontario.[4] Numerous high level beaches with outlet channels for the flood waters have been observed in other parts of the great lakes.[5] Similar evidence shows that the highlands between Hudson Bay and James Bay[6] and parts of Greenland were covered by the sea.[7] It is even believed that the whole of the continent was submerged during this closing stage of the Quaternary.[8] Southwards in Cuba,[9] and far out in the Pacific in the Hawaiian Islands it attained at least a depth of from 500 to 1,000 feet.[10]

Europe.—The Cromer Till, on the coast of Norfolk, is overlain in some places by interglacial gravels. Above these are the Contorted Drift, Boulder Clay, and beds of stratified flint and gravel. The Contorted Drift preserves the effects of the stranding of icebergs which broke away from the glaciers during the initial stages of the episode. The Upper Boulder Clay represents the fluvio-glacial deposits of other districts. The overlying sands, "coarse and fine," show the diminishing rate of flow of the water as the level of the North Sea rose and checked its velocity and submerged the district. The high cliffs of this coast reveal the enormous denudation to which the surrounding districts were subjected by the torrents which swept over them.

[1] A. de Lapparent, *Traité de Geol.*, 5th ed., 1906, p. 1719.

[2] C. E. Dutton, "Tert. Hist. Grand Cañon District." *U.S. Geol. Sur., Mono.* ii., 1882, p. 100.

[3] R. W. Ells, "Sands and Clays of the Ottawa Basin." *Bull. Geol. Soc. Am.*, vol. ix., 1898, p. 222.

[4] A. P. Coleman, "Marine and Fresh-water Beaches of Ontario." *Bull. Geol. Soc. Am.*, vol. xii., 1901, p. 129.

[5] F. B. Taylor, "Correlation of Erie-Huron Beaches." *Bull. Geol. Soc. Am.*, vol. viii., 1897, pp. 31, 58.

[6] R. Bell, "Occurrence of Mammoth and Mastodon Remains around Hudson Bay." *Bull. Geol. Soc. Am.*, vol. ix., 1898, p. 386.

[7] D. White and C. Schukert, "Cretaceous Series of the West Coast of Greenland." *Bull. Geol. Soc. Am.*, vol. ix., p. 368.

[8] Dr. J. W. Spencer, "Post-Tertiary Deposits of Manitoba, Discussion on." *Bull. Geol. Soc. Am.*, vol. i., 1890, p. 409.

[9] Dr. J. W. Spencer, "Post-Pliestocene Subsidence *versus* Glacial Dams." *Bull. Geol. Soc. Am.*, vol. ii., 1891, p. 465.

[10] Dr. J. W. Spencer, "Geographical Evolution of Cuba." *Bull. Geol. Soc. Am.*, vol. vii., 1895, p. 94.

It was at this time that the Chalk Downs received their present contours or nearly so. The Wealden of Kent and Sussex was an anticlinal dome towering high into the air during Interglacial times. It had been denuded during the Pliocene epoch to some extent, but this was continued at this time, and only a fringe remains to record its former dignity. The escarpments of the North and South Downs are what remain of the dome. The central portion has been carried away to form the bottom of an adjacent sea, or the top soil of some neighbouring heath or meadow land. After the waters of the submergence had retired, the Weald formed an extensive inland sea, which eventually eroded the valleys of the Medway and other rivers, and drained the basin.

"The whole of the features of the Weald are such as are to be explained by subaerial denudation," [1] so that it is difficult to suppose that the few streams which now drain the area have carried away such an enormous depth of strata over the large tract of country from which it is undoubtedly missing. "Great as are the effects

Fig. 52.—Section, 45 miles in length, to illustrate Denudation of the Weald.

of rain, rivers, and running water, they are insignificant as compared with the vast denudation which was effected during the last stage of the glacial epoch." We have not only to account for the erosion of one area, but the formation of high cliffs and eskers in others at the same time. Subaerial waste may account for the former, if sufficient time be allowed, and facilities are forthcoming for the removal of the eroded material, but it will not explain the other. The present configuration of the Weald is more rationally explained by the great torrents which in other localities built up the kames or eroded cañons. The free communication between England and Europe of Quaternary times was now interrupted by the erosion of a waterway through the Straits of Dover.

Allied to the terraces and "contemporaneous with the great kames" are the Carse clays of the Scotch Rivers. The volume of the streams which deposited these clays, and the quantity of material carried by them, may be gathered from the extent of the deposits themselves. In the Tay valley alone, "it covers an area of no less than 35 square miles to a depth of 10 to 40 feet or more. To this must be added the material swept out to sea, and what has subsequently been denuded" [2] from exposed positions. The

[1] W. Topley, "The Geol. of the Weald." *Mem. Geol. Sur. Eng. and Wales*, 1875, p. 300.
[2] Sir A. Geikie, *Prehistoric Europe*, p. 386.

torrential character which these rivers assumed is seen in the masses of shingle which they carried along, and the tumultuous bedding which the high-level shingles reveal.

Asia.—In places towards the Polar regions the ice seems never to have been completely dispersed. It is probable that the Arctic areas have been clothed with ice since the Pliocene uplift. "Perhaps one of the most singular features of the glacial deposits of Russia is to be found in the sheets of ice which, underlying and interstratified with the clays, have survived as actual fossil remains of the ice sheets of the Pleistocene ages, along the low-lying grounds of the coast region of Siberia and in the opposite islands of New Siberia."[1] Mr. Wright has described a similar remnant of the old sheet. At Elephant Point a ridge, 2 miles wide and 250 feet high, is chiefly composed of solid ice overlain with clay and vegetable mould. At a depth of a foot beneath the upper surface there is a solidly frozen stratum consisting of bog moss and vegetable mould, which must

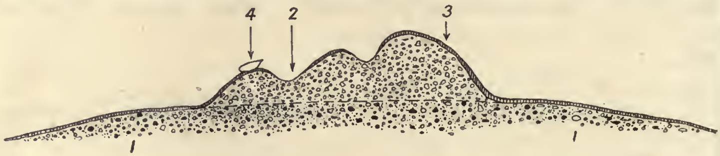

Fig. 53.—Section across Old Moraine (1), long narrow ridge of Drift (2), with Loess covering (3), and erratic block (4) in Turkestan. (R. W. Pumpelly, *Exploration in Turkestan*, p. 134).

have been carried there by some means. It evidently represents the Upper Boulder Drift of other localities, and owes its formation to similar causes.

Traces of the post-Quaternary transgression are scattered over the whole of the most northerly parts of Asia.[2] The distribution of the loess of North-West China is explained by a temporary submergence of the land, about 3,000 feet, which extended through Siberia, Turkestan, and Russia in Europe.[3] Perched erratics, high-level river shingle, and recent pebble beds at altitudes of 2,500 to 2,700 feet, in the Himalayas, appear to indicate its extension southwards.[4] The low-level laterite of the coastal regions of India is a conglomerate consisting to a large extent of fragments of the earlier formation washed down and cemented together, and containing implements of Palæolithic age.

[1] Sir A. Geikie, *Text-book of Geol.*, 4th ed., 1903, p. 1339.

[2] E. Suess, *The Face of the Earth*, 1904, vol. iii., p. 20.

[3] G. F. Wright, "Loess in Northern China and Central Asia." *Bull. Geol. Soc. Am.*, vol. xiii., 1902, p. 135. Sir R. I. Murchison, *Geol. of Russia and Ural*, 1846, p. 524.

[4] H. H. Hayden, "Geol. of Provinces of Tsang and Ü in Tibet." *Geol. Sur. India, Mem.*, vol. xxii., part 2, 1905, p. 167. A. B. Wynne, "Geol. of the Salt Range in the Punjab." *Geol. Sur. India, Mem.*, vol. xiv., p. 114.

The Quaternary history of Turkestan relates the occurrence of similar events. Long, narrow and irregular steep mounds lie upon the middle of older and smoothed off moraines or in river channels. Both the new kame-like ridges and the old moraines are covered with loess, and have many large erratics strewn upon their surface. This is illustrated diagrammatically in the accompanying sketch (Fig. 53). Terraces are of wide extent, and are attributed to an extensive and uniform cause, either of successive warping of the crust or climatic change, and in this they are in harmony with the Quaternary geology of other countries.

Africa.—Extensive tracts of plateau country throughout Cape Colony were eroded into ranges and isolated sections. They obviously once formed a continuous tableland, which was denuded at a period when the rivers flowed at some 600 to 1,000 feet above their present levels. The isolated hill tops reach a more or less common level of 800 to 1,200 feet above sea level.[1] They are capped by high-level terrace gravels, which sometimes lie as high as 2,000 feet. In all cases the gravels are coarser near the mountains than further away from them, and sometimes contain boulders of great size, up to 4 and 5 feet in diameter, which have their edges rounded.[2] The smaller fragments are more rounded and well water-worn. Beneath the more recent alluvium of the greater river valleys, the terrace gravels are difficult to distinguish from the high-level ones, and were formed at the same time.[3] They cover extensive areas, and are of great depth, sometimes 120 feet, and have been "gathered from nearly all the rock systems of Cape Colony." The shells hitherto found in these deposits "all belong to existing species."

These terrace plains and boulder-strewn valleys seem to have been the work of sheet floods similar to those which produced eskers and sand plains.[4] Great torrents flowed over wide areas of the Colony, deep enough to leave gravel as high as 2,000 feet above sea level, and strong enough to roll 5 feet boulders. In some places where the currents were impeded by mountain ridges the gravels were heaped up to a considerable extent,[5] while the water cut its way through the softer ground, and carved out the valleys where the later alluvium now lies. Similar alluvium lies in isolated patches in the Sahara Desert.[6]

Australia.—Similar drift gravels, from 100 to 120 feet in thickness, are found in Queensland above high-water mark. They are estuarian deposits, and contain shells consisting entirely of species still living in the adjoining seas.[7] The post-Tertiary mammalian remains already alluded to are associated with these shells, and it is suggested

[1, 2] A. W. Rogers, *Geol. of Cape Colony*, 1905, pp. 352, 355.

[3, 5] *Ibid.*, pp. 363, 365.

[4] W. H. Davies, "Observations in South Africa." *Bull. Geol. Soc. Am.*, vol. xvii., p. 397.

[6] A. de Lapparent, *Traité de Geol.*, 5th ed., 1906, p. 1719.

[7] R. L. Jack and R. Etheridge, *Geol of Queensland*, 1892, p. 617

that a great submergence has occurred at a comparatively recent date to account for the peculiarity of the combination.[1]

New Zealand.—At the close of the Quaternary epoch in New Zealand a "period of destruction commenced, during which the flood plain was benched into terraces, as we now see them in the Cromwell basin."[2] It was at the final retreat of the Kawarau glacier that a confused mass of river drift and morainic matter was scattered in its wake. The floods cleared many valleys which had hitherto been choked with morainic debris. The lower glacial series was enormously denuded and swept away, the part remaining being furrowed into valleys, some of them 150 feet deep. The Till has been re-assorted and denuded to an enormous extent. "High-level gravels occur between the 1,000- and 1,200-foot contours. These isolated gravels perched high up in the valleys are merely remnants of an ancient flood level that escaped destruction at the time the rivers benched and excavated the valleys and basins along their course down to present contours," and the remnants indicate that one river at least was as much as 10 miles wide.

Height and Duration of Submergence.—The fact of the last transgression is of greater import than the proportions it attained. The relative levels of sea and land were different at that time than now, so that it is impossible to say what the average depth of the submergence was. A point which was high above sea level then may be lower now, and *vice versâ*. There are, therefore, no means of ascertaining the relation of the level of the water with the present sea level. It is only possible to record the depth at particular points with reference to the existing sea level. The evidence to which we appeal includes the high-level fossiliferous sands and clays, the altitudes to which the erratics were floated by the icebergs, and the heights attained by the loess.

The most reliable evidence of the depth of water upon continental land is afforded by the clays and silts with marine fossils. They occur in many parts of North America and Northern Europe, and are confined to coastal localities. The fact that the shells are often found *in situ* appears to be decisive, and Sir A. Geikie says "there seems, therefore, no reason to doubt that the submergence reached as far as the 500-foot limit."[3] Above this level the evidence is neither so general or so clear, but it is very suggestive. The stratified sands with shells *in situ* rise to 1,000 feet and over in Wales,[4] and similar stratified sands exist at altitudes of from 1,200 to 1,300 feet in Ireland.[5] Shells of the same age have been recorded at 5,000 feet

[1] R. L. Jack and R. Etheridge, *Geol. of Queensland*, 1892, p. 618.
[2] James Park, "The Geol. of the Cromwell Subdivision." *Geol. Sur. New Zealand, Bull.* 5, p. 45.
[3] Sir A. Geikie, *Text-book of Geol.*, 3rd ed., 1903, p. 1319.
[4] Sir A. C. Ramsay, *Geol. Gt. Bt. and Ireland*, 1878, p. 417.
[5] A. J. Jukes Browne, *Building of British Isles*, 1911, p. 440.

at Pinnacle Pass in the United States,[1] and many other instances might be stated of a similar nature.

The maximum depth of the submergence may be gathered from the position of many of the perched blocks. "Granite boulders are abundant on the Pocono Plateau, 2,000 feet above the sea." [2] The Macetown erratic in Otago, New Zealand, "must have been carried over mountains 6,000 feet high." [3] Similar boulders occur at a height of 4,200 feet in the Rocky Mountains. Their origin has been traced to the Laurentian Plateau of Eastern Canada, the maximum height of which is 1,600 feet. The sea which floated the icebergs and transported these erratics high up in the Rockies drowned the Laurentian axis to a depth of 2,600 feet at least. Prof. Wright has quoted a number of instances of erratics, which have been floated over acclivities 3,000 feet in altitude, or have been left reposing at that height.

The high-level stratified gravels are also supposed to indicate the depth of the submergence at the close of the Quaternary epoch. "In Wales it was no less than 2,300 feet." [4] Drift consisting of sand and gravel, rudely stratified, occurs in many parts of North Wales. They have also been observed at an altitude of 5,300 feet in the Porcupine Hills of North America.[5]

The water which held the fine matter in suspension, which now forms the loess and brick earths, may have stood at a higher level than is reached by that formation. In parts of China it attains an altitude of from 4,000 to 7,000 feet.[6]

The position of the high-level silts, gravels, and loess, together with the movements of the erratic and perched blocks, show that from North America to China and New Zealand the submergence may have approximated to the 6,000-foot level. Measured by ordinary standards, this is a phenomenal depth, but, as was pointed out in the opening chapter, the oceans are but a film upon the surface, compared with the earth's diameter, so that this and previous submergences were but a heavy dew upon the surface of our planet.

The time occupied by the submergence is not so readily determined. The initial torrents were necessarily rapid in their action, since gravel requires water in swift motion for its formation. The loess, which represents the final phase, "bears evident marks of sudden transport." [7] And this is confirmed by the undecomposed

[1] J. D. Dana, *Manual of Geol.*, 4th ed., 1895, p. 984.

[2] G. F. Wright, *Ice Age in North America*, 1911, pp. 241, 244, 247.

[3] James Park, "The Geol. of the Queenstown Subdivision." *Geol. Sur. New Zealand, Bull.* 7, 1909, p. 31.

[4] Sir A. C. Ramsay, *Old Glaciers of Switzerland and North Wales*, 1860, p. 96.

[5] G. M. Dawson, "Glacial Deposits of S.W. Alberta." *Bull. Geol. Soc. Am.*, vol. vii., 1896, p. 63.

[6] Bailey Willis, *Research in China*, vol. i., part 1, 1907, p. 194.

[7] H. T. de la Beche, *Researches in Theoretical Geol.*, 1834, p. 389

condition of many of the carbonate, silicate, and quartz fragments which it contains. Had it been slowly deposited under water as an ordinary sediment, it would have assumed a more distinctly stratified structure. There is, therefore, no evidence that the waters of the submergence remained for any length of time upon the interior, and the only safe deduction that can be made from the geological evidence is that the episode was a comparatively brief one, and that the events followed one another somewhat closely.

Quaternary and Recent Denudation Compared.—The erosion effected at the two stages of the Quaternary glaciation has been continued in a minor degree down to the present time. Recent glacial erosion has, however, been much more restricted, both in area and time, when compared with what took place during the Great Ice Age, and although the powers of atmospheric waste have persisted in their attacks upon the rocks ever since that time, the results are insignificant when compared with the Drift. The agents of subaerial denudation, although effective, have left no such marked evidence of their handiwork. Lake basins formed during the glacial period, and situated in areas which favour the action of air, rain, frost, rivulets, waves, tides, and other powers of waste, have not yet become silted up, although the process has been going on for so many ages. These agents of decay have been incessantly at work since the close of the ice age, yet the resulting deposits do not compare with the Drift in bulk. The silt which accumulates in lakes and estuaries, the sand and mud which form river deltas, and the shore deposits which surround all continents, do not aggregate a tithe of the continental drift deposits.

The presence of the glacial markings themselves are a proof that ordinary subaerial denudation, since the Pliocene uplift which brought on the glacial erosion, has been insignificant. The mountains themselves which have experienced the greatest degree of denudation were not in being before that event. The subaerial erosion since then has been trifling, or the marks of the ice movement would have long since been obliterated in exposed places. In many instances, however, "from mountain top to below sea level, the ice-worn polish, striæ, and grooving are often as fresh as those by the side of a living glacier."[1] This can only be said of the most durable of rock surfaces. It is amongst the less durable of rocks that the subaerial forces have been most destructive. Here the striæ have been more or less erased. The fine material has been carried out to sea suspended in river water, and has added to the littoral deposits being laid down in the ocean bed.

The Miocene uplift, it is evident, was the controlling factor in determining the present configuration of the landscape. The main features were much what they are still before the glacial denudation. During the ice age the details were reduced in level and

[1] Sir A. Geikie, *Scenery of Scotland*, pp. 276, 388.

modified in contour. "The position into which they were thrown by the contortions and dislocations have in many cases materially guided the powers of waste in the long process of superficial degradation." The modification produced by the Pliocene glaciers has been continued in a very minor degree by the powers of atmospheric waste.

Frost and snow in their season split up the solid rock into fragments. The corners are rounded off, and the edges removed as they find their way down the hill sides in the form of screes. The chemical properties of rain water further reduce them. The fine matter worn off is constantly being carried in suspension or solution in strong river currents, until the sand and silt (the waste of far-distant peaks) are deposited in deltas, and the soluble salts carried out to sea and deposited in the terrigenous muds which line the oceans. These erosive agencies work steadily in concert, and slowly reduce the height of many of the mountains, and carve out valleys.

Earth still Growing.—The accumulation of organic sediments has proceeded with these processes of decay. The formation of vegetable mould and ocean muds, combined with the products of atmospheric degradation, have produced new sediments, so that the earth is growing imperceptibly larger as the ages of its history roll on. The radiant energy from the Sun and other sources is continually being received and stored up through the organic processes.

Conclusion.—Through many and long cyclic changes the world has thus grown to its present state. The character of its outline and beauty of its scenery have been determined. The infinite diversity of its landscape, sea and land, wide-stretching plain and towering cliff have all come into being. They have been moulded and fashioned by the succession of changes that have taken place since the foundation of the earth was laid beneath the primæval ocean. The earth has become habitable for man. Its scenery pleases his taste, and the problem of its genesis and evolution has excited his imagination and promoted mental exercise.

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